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Electronic Manufacturing Process Improvement (EMPI) For Printed Wiring Assemblies

Program Task 3: Experimental Results

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ROBERT CROSS Project Manager	DATE

David J. McLaine	14 Feb 92
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13. ABSTRACT

This Task 3 Technical Operating Report is comprised of three basic sections. The first section is an overall description of the Electronic Manufacturing Process Improvement (EMPI) for Printed Wiring Assemblies (PWAs) Program. Included is a description of the PWA design, continuous process improvement, and the seven basic experimental approach. The second section presents the results obtained by performing the statistically designed experiments described in the second technical report for this Electronic Manufacturing Process Improvement Program, "Program Task 2 Project Description Report," dated February 1991. The second section also presents the analyses performed on those results, and identifies the process capability indices (Cp and Cpk) for the seven processes evaluated. It includes a discussion and condusion of the analyses, and process capability indices determined from the experimental data. It describes the final, statistically designed experiment that is being run as the wrap-up to this phase of the EMPI for PWAs Program. This experiment will be run to demonstrate and quantify the process improvements achieved as a result of applying design of experiments (DOE) methodology to TRW-MEAD's surface mount printed wiring assembly operation. The third section is the Appendices which contain the Cost Benefits Analysis for this program and the finalized detailed experimental plans for the seven experiments run under Task 3 of this program. The raw data and the spreadsheets used to calculate the ANOVA and Cpk values for each experiment are being supplied on 5-1/4, MS-DOS disks in a format compatible with the LOTUS 123 and Microsoft Works programs.

14. SUBJECT TERMS

Printed Wiring Assemblies (PWAs), Electronic Manufacturing Process Improvement (EMPI), Design of Experiments (DOE), Printed Wiring Board (PWB), Solder Joint, Tinning, Fine Pitch Device (FPD).

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1. OVERALL OBJECTIVES AND GOALS

TRW's goal in performing the Electronic Manufacturing Process Improvement (EMPI) project is to identify, quantify (through process capability indices), and optimize significant process variables used in the surface mount printed wiring assembly of military avionics hardware. The resulting improvements in the processes, and the methodologies used to achieve these improvements, will directly benefit TRW MEAD. In addition, through an Industry Days presentation, the methodologies and improvements realized through the application of DOE and continuous process improvement (CPI) will be offered to industry in general.

Covered by this study are five subtasks: (1) infrared reflow of printed wiring assemblies (PWAs); (2) fine pitch device (FPD) lead tinning; (3) cleaning (which includes a component standoff experiment and a solvent cleaning experiment); (4) FPD lead forming; and (5) placement (which includes a solder paste placement experiment and a component placement experiment).

This project has included all of the potentially significant process variables that are controlled and determined outside of the workstation in which the specific experiment is being run (interstation variables). These include significant process and equipment variables that are not monitored or controlled at the workstation being used in the specific experiment. These variables may still contribute directly to that workstation's yield. An example of an interstation variable would be the PWB thickness which is controlled by the PWB fabricator, according to TRW MEAD engineering drawing requirements. This variable influences the reflow process yield by introducing variations in the heat required to reflow the PWA due to variation in the mass of the PWB.

The value of the EMPI for PWAs program cannot be reported without a cost benefits analysis. The model for this analysis has been developed as well as a goal for the cost benefit for the program. This analysis is presented in Section 2.

1.1 PRINTED WIRING ASSEMBLY DESIGN

1.1.1 Printed Wiring Board Design

A Standard Electronic Module (SEM), Format E size was selected for this EMPI study. This format, approximately 5.6 in. by 5.2 in., has become a standard for electronic modules currently being developed for Air Force integrated avionics applications. Polyimide-glass with 1/2-oz/ft^2 copper foil outer layers and two inner layers of 2-oz/ft^2 copper foil were used in the construction of the PWB. The mass of copper selected simulates the thermal characteristics of copper-Invar-copper, constraining layers, without imposing the cost penalty associated with it.

The footprint patterns used for several components associated with this design were taken from TRW MEAD's design standards. Vias, power and ground connections, and power/ground layer clearances were provided for component pins; however, no circuit interconnections were provided. These interconnections are not considered to be relevant to any of the studies being performed. The power and ground pin connections are significant because of the different thermal affect they have on solder joint formation compared to the affect of component pads that are not heat-sinked to internal power/ground planes.

Different PWB styles were fabricated in order to determine the affects these styles would have on the PWA assembly process. These styles are discussed in some detail in the second technical report for this program. Essentially these different styles were associated with the thickness, plated finish, component standoff, and "stretch" of the PWB. The complete documentation package for the several PWBs were presented in the second technical report for the program.

1.1.2 Component Selection

The selection and placement of components on the PWB was made after first considering the different types of components that would be expected on a "typical" TRW MEAD avionics SEM-E design. Their locations on the PWB were chosen to provide the most beneficial experimental data for this EMPI program. Figure 1, EMPI PWA Layout, depicts these locations. A parts list was presented in the second technical report for this program.

1.2 CONTINUOUS PROCESS IMPROVEMENT

The goal of this EMPI for the Printed Wiring Assemblies program is to understand and quantify the process variables that have significant affects on process responses that are critical to the manufacture of military avionics printed wiring assemblies. The measures of this are the process capability indices known as Cp and Cpk. Cp is an index that measures the variation in a process. Cpk is an index that measures how well a process fits within a required process "window." Experiments are designed around the PWB assembly processes in order to arrive at values for these process capability indices. For this program there are five subtasks that involve a total of seven experiments. Each of the experiments requires the application of the DOE methodology. This experimental design process methodology consists of five basic steps that are described as follows:

1.2.1 Step 1

The first step is to identify the process flow to be studied. This was done as a part of the Task 1 Baseline phase of the program and is presented here as Figure 2, EMPI Process Flow Diagram. The identified workcells are the "core" of the PWB assembly process at TRW MEAD. The subtasks outlined by the heavier weighted lines are those intercell processes being investigated by this program.

1.2.2 Step 2

The second step in the process identifies critical process responses, or outputs, and all suspected process variables or inputs that influence the responses. This was accomplished at a brainstorming session attended by process and manufacturing engineers and technicians that were familiar with the assembly process and equipment. The output of this step was a "Cause and Effect" diagram for each of the seven experiments and were the foundations of the designs for those experiments. These "cause and Effect" diagrams are presented in each of the detailed experimental plans which can be found in Section 2 to this report.

1.2.3 Step 3

The third step in the process quantifies the process and response variable requirements and establishes the measurement method used to collect the data for the experiments. The requirements for the process and response variables have been taken, for the most part, from the frequently imposed contractual requirement, MIL-STD-2000. Since this EMPI program was begun in August of 1990, this standard has been revised to level "A;" and many of the original requirements have been deleted. Where MIL-STD-2000 had no applicability to he manufacturing process, internal process specifications and workmanship standards were used.

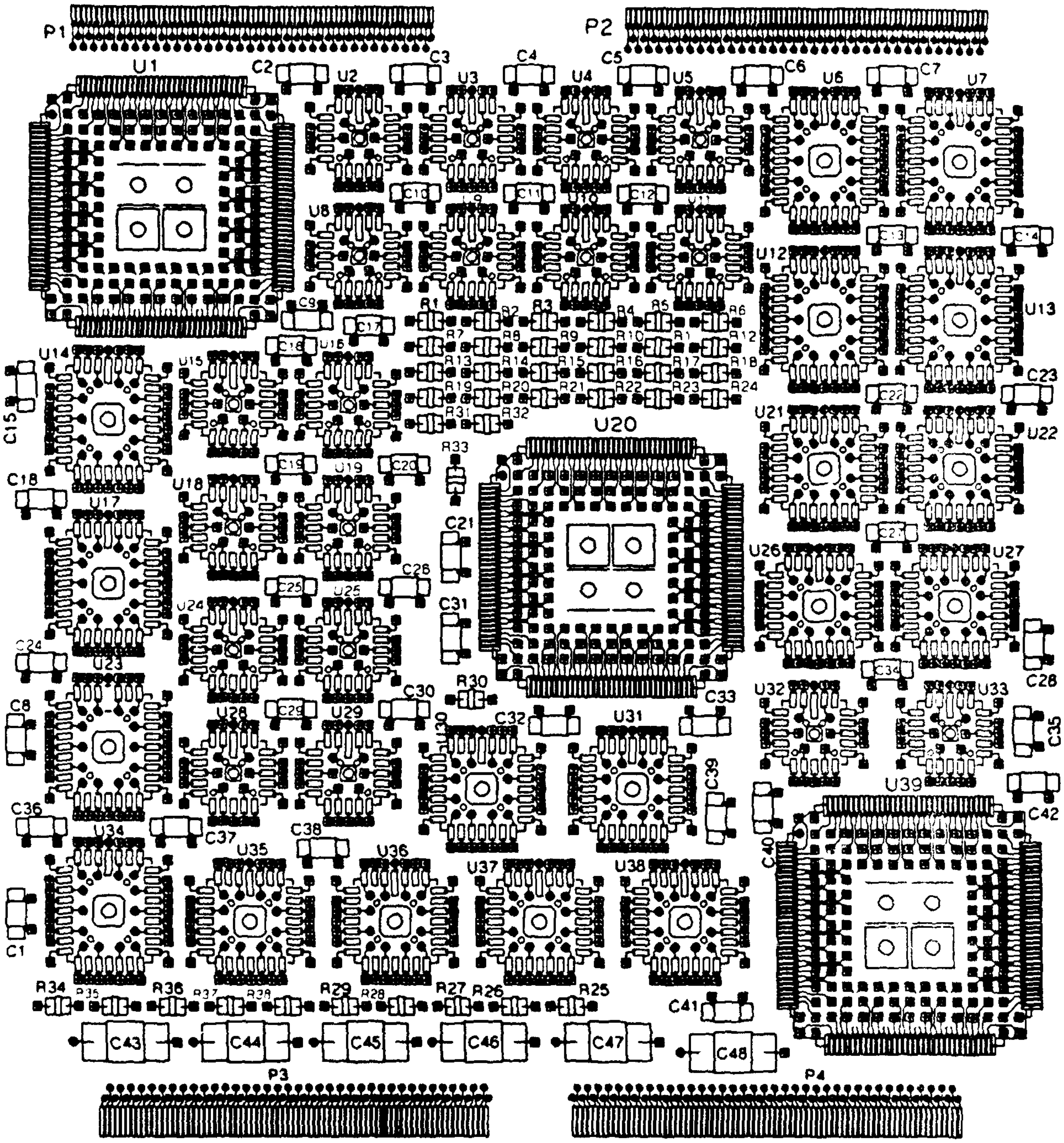

Figure 1. EMPI PWA Layout

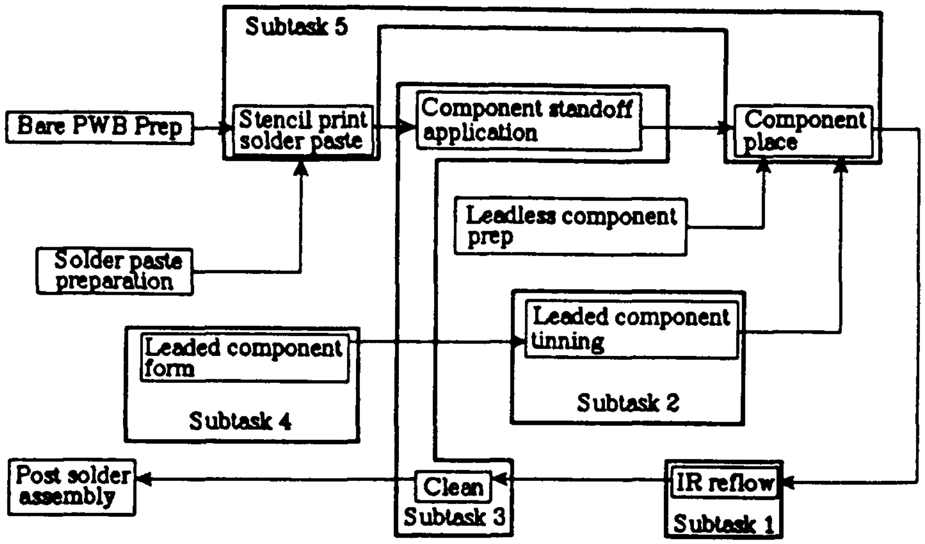

Figure 2. EMPI Process Flow Diagram

1.2.4 Step 4

The fourth step in the process establishes the relationships between the process variables and responses for each experiment to be performed. This is an important step in the DOE process. It identifies the "recipe" for each run of each experiment. This relationship is determined by establishing a process and response variable matrix. It is at this point that selection of the type of experimental design is determined. Where three or fewer process variables are being examined, the selection of a full factorial design is warranted, because the number of experimental runs is not prohibitive. Where more than three, but less than eight, process variables are chosen, a fractional factorial experimental design is considered. The assumptions that are made for the fractional design are that there are no interaction effects among the process variables and that the effects of the process variables on the response are linear. These assumptions must and can be tested for the fractional factorial designs by running a reflected (or folded) design which identifies interactions if they exist. Since the goal of the experiment is to detect linear changes in a response due to changes in a particular process variable, the experimental designs are based on a two-level process variable scheme. The detailed experimental matrix can be represented by a classic "1-2" matrix with the response to be observed and the process variables to be exercised heading the columns with the experiment run numbers leading the rows. This matrix gives the exact recipe for each experimental run. An excellent reference for this experimental design methodology may be found in "Designing for Quality" by Robert Lochner and Joseph Matar, ASQC Quality Press. See Figure 3 for an example of an eight run experimental matrix.

Full factorial designs should be replicated at least once to enable the variability of the response variables and the experimental error to be established. It is this response variable variability that is used to determine the process capability index for the process being measured.

Random Order Trial Number	Standard Order Trial Number	Response Observed Values	A		B		C		AB		AC		BC		ABC	
			1	2	1	2	1	2	1	2	1	2	1	2	1	2
	1															
	2															
	3															
	4															
	5															
	6															
	7															
	8															
TOTAL																
NUMBER OF VALUES																
AVERAGE																
EFFECT																

Figure 3. Eight Run, Two Level Experimental Matrix Response

Fractional factorial designs require that a reflected experiment be run in addition top a replicated run. This is due to the fact that process variables are assigned to columns in the matrix that would normally be assigned to collect interaction effects. Any significant effects associated with these columns must be identified as due to interactions or due to the interloping process variable. If neither direct or interactive effects are noted, the data in these columns may be used to measure experimental error. This error will give an experimenter an indication whether or not a significant process variable has been overlooked.

The data which is gathered from the experiment is subjected to an analysis of variance (ANOVA) which is described in Section 2 to this report. The main thrust of this third technical report is to detail the results of applying this third step of the DOE process to the EMPI for the Printed Wiring Assemblies program.

1.2.5 Step 5

The fifth and final step in this process implements the results obtained. Process variables that need to be improved, as determined by the analysis of the experimental data, will be implemented, as indicated, and verified by additional experimentation. The process variables that are identified as being required to be brought under control will be brought under control. The limits of that control will also come from the analysis of the experimental data.

Many of the process variable limits that are equipment related are monitored in a closed loop fashion by the equipment. This lends itself to automated tracking and reporting since the process variable data can be systematically processed by an automated shop floor management system. Other process variables need to be manually tracked and entered into the shop floor management system.

The Total Quality Management TQM methodology implemented by this EMPI program implies that there is a never ending process improvement cycle in place. Data is provided by the implementation of DOE to indicate where improvement can best be made, and advantage must be taken of that information constantly if TQM is to be meaningful.

1.3 DESCRIPTION OF EXPERIMENTS

The finalized versions of the seven detailed experimental plans are presented in Appendix H to this report. These plans have changed somewhat since they were first presented in the Second Technical Report to this program. These changes include the final details of the data to be collected, the equipment that is used, and the process and response variable specification limits.

The basic structure of the detailed experimental plans is: (a) introduction; (b) cause and effect diagram; (c) process and response variable details, (d) list of materials, supplies, tools, and equipment; (e) experimental procedure; and (f) examples of data collection sheets for the response variables.

2. DATA ANALYSIS (ANOVA)

2.1 SUBTASK 1, INFRARED REFLOW EXPERIMENT

The details of the infrared reflow experiment are presented in Appendix B to this report. The thrust of the experiment is presented in Figure 4. The data collection for the fine pitch device soldered lead heel fillet height, lead dewetting, solder volume, and solder balls have not been gathered as of the date of this report. This data and analysis will be presented in the final report to this program.

This subtask involved three eight-run experiments in seven process variables. These seven process variables are encircled in Figure 4. Two of the experiments were replications run to determine the variability of the process. The third experiment was a reflection of the replicates, and it was run to determine whether interactions existed among the process variables. The PWB thickness process variable shown in Figure 4 was used in a single point experiment investigating the affect of PWB thickness on solder joint temperature.

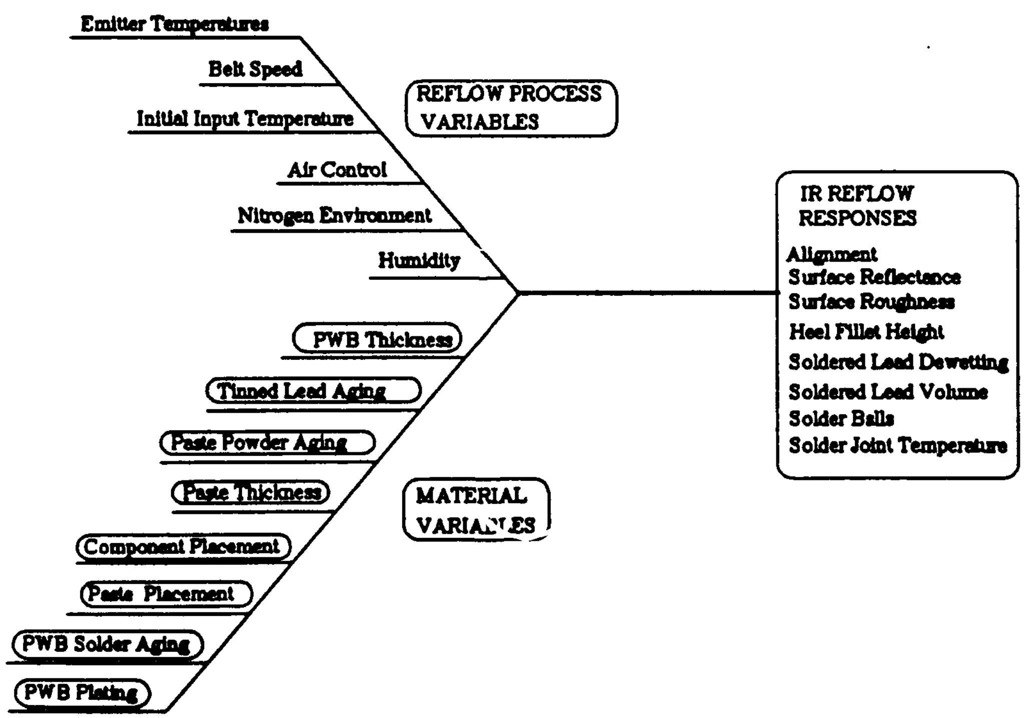

Figure 4. Infrared Reflow Subtask Cause and Effect Diagram

2.1.1 Reflowed Solder Joint Reflectance

2.1.1.1 Effects

2.1.1.1.1 Analysis. The effects on the FPD response variable, Solder Joint Reflectance, are presented in Tables 1 and 2. Figure 5 is a normal plot of the ranked effects taken from Table 1. Table 3 is a tool that is used to determine whether or not effects associated with process variables that have been assigned to interaction columns in a fractional factorial matrix design are real or due to interactions.

Similarly, the effects on the LCC response variable, Solder Joint Reflectance, are presented in Tables 4 and 5; and the normal plot of these Table 4 effects are shown in Figure 6. Table 6 is the discriminator between real and interaction effects.

The response table worksheets see Table 1 for a description of the spreadsheet) average the high and low responses associated with each process variable being tested; the effect for each process variable is the difference between those averaged high and low values. The greater the difference, relative to the other process variable effects, the greater the affect that variable has on the response variable. The effects are ranked from lowest to highest and plotted on a normal distribution graph. Data points on the upper end of the plot that lie to the right of an imaginary straight line drawn through points in the middle of the plot, indicate significant effects. Similar significance is associated with points that lie to the left of the estimated straight line on the lower end. These points are regarded as significant because they cannot be attributed to normal variation. A description of this analysis technique is presented in "Designing for Quality", by Lochner and Matar, ASQC Quality Press.

The interaction worksheet combines, subtracts, and compares the results of process variable effects found in the normal and folded experimental runs of fractional factorial designs. Significant, combined normal and folded process variable effects associated with the AB, AC, BC, and ABC locations that are insignificant when the folded design effect is subtracted from the normal design effect, may be assumed to be a real effect and not an interaction. If this is not the case, then the effect certainly includes an interaction between the appropriate A, B, and C process variables.

2.1.1.2 ANOVA

2.1.1.3 Capability Indices

The process capability indices, Cp and Cpk, are a measure of the "goodness" of a process in terms of yield. In every case, the bigger the Cp and Cpk values, the better the yield and thus the better the process. Cp is a measure of the variability of a process compared to the specification limits for the end product of that process. A Cp of 1 indicates that the process yields product that has a +/- 3 sigma variability that is the same as the specification limit variability for the process. Cpk of 1 adds to the Cp of 1 by indicating that not only are the +/- 3 sigma variabilities of the process and the specification limits of the product equivalent, but also that the mean of the process variability is the same as the mean of the product specification limits. The Appendix section to the Task 2 Volume titled "Guidelines for Calculating EMPI Process Capability Indices" to this report presents the derivation of the Cp and Cpk values as they are used here. Since Cp does not give the measure of process capability that is desired in this program, Cpk will be used for that measure.

Table 1. Effects Table, Normal Design Solder Joint Reflectance, FPDs

Std Order Trial No.	Observed Response Variables: Normal	Replic	Avg.	A Stencil Thickness, mils: 4/10	10/14	B Powder Aging, hours/95C: 0	24	C Lead Steam Aging, hours: 0	8	AB Paste Deposit Offset, mils: 0/0	-3/-3	AC PWB Lead Steam Aging, hours: 0	8	BC Component Offset, mils: 0/0	3/3	ABC PWB Style: fused	leveled
1	2.000	1.100	1.550	1.550		1.550		1.550			1.550		1.550		1.550	1.550	
2	1.100	1.000	1.050	1.050		1.050			1.050		1.050	1.050		1.050			1.050
3	2.000	1.800	1.900	1.900			1.900	1.900		1.900			1.900	1.900			1.900
4	1.000	1.800	1.400	1.400			1.400		1.400	1.400		1.400			1.400	1.400	
5	1.000	1.800	1.400		1.400	1.400		1.400		1.400		1.400			1.400		1.400
6	1.200	1.000	1.100		1.100	1.100			1.100	1.100			1.100	1.100		1.100	
7	1.200	1.100	1.150		1.150		1.150	1.150			1.150	1.150		1.150		1.150	
8	2.000	1.200	1.600		1.600		1.600		1.600		1.600		1.600		1.600		1.600
Total			11.15	5.90	5.25	5.10	6.05	6.00	5.15	5.80	5.35	5.00	6.15	5.20	5.95	5.20	5.95
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.394	1.475	1.313	1.275	1.512	1.500	1.288	1.450	1.338	1.250	1.538	1.300	1.488	1.300	1.488
Averages Effect (1<2>-1<1>)				-0.163		0.238		-0.213		-0.113		0.288		0.188		0.188	

Table 2. Effects Table, Folded Design Solder Joint Reflectance, FPDs

Random Order Trial No.	PWB Serial No.	Resp Obs Values	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	leveled
6	1005	1.10		1.10		1.10		1.10	1.10		1.10		1.10			1.10
4	1011	1.60		1.60		1.60	1.60		1.60			1.60		1.60	1.60	
8	1006	1.00		1.00	1.00			1.00		1.00	1.00			1.00	1.00	
2	1012	1.00		1.00	1.00		1.00			1.00		1.00	1.00			1.00
1	1019	1.30	1.30			1.30		1.30		1.30		1.30	1.30		1.30	
5	1013	1.10	1.10			1.10	1.10			1.10	1.10			1.10		1.10
7	1020	1.00	1.00		1.00			1.00	1.00			1.00		1.00		1.00
3	1014	1.10	1.10		1.10		1.10		1.10		1.10		1.10		1.10	
Total		9.20	4.50	4.70	4.10	5.10	4.80	4.40	4.80	4.40	4.30	4.90	4.50	4.70	5.00	4.20
No. of values		8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average		1.15	1.13	1.18	1.03	1.28	1.20	1.10	1.20	1.10	1.08	1.23	1.13	1.18	1.25	1.05
Effect			0.05		0.25		-0.10		-0.10		0.15		0.05		-0.20	

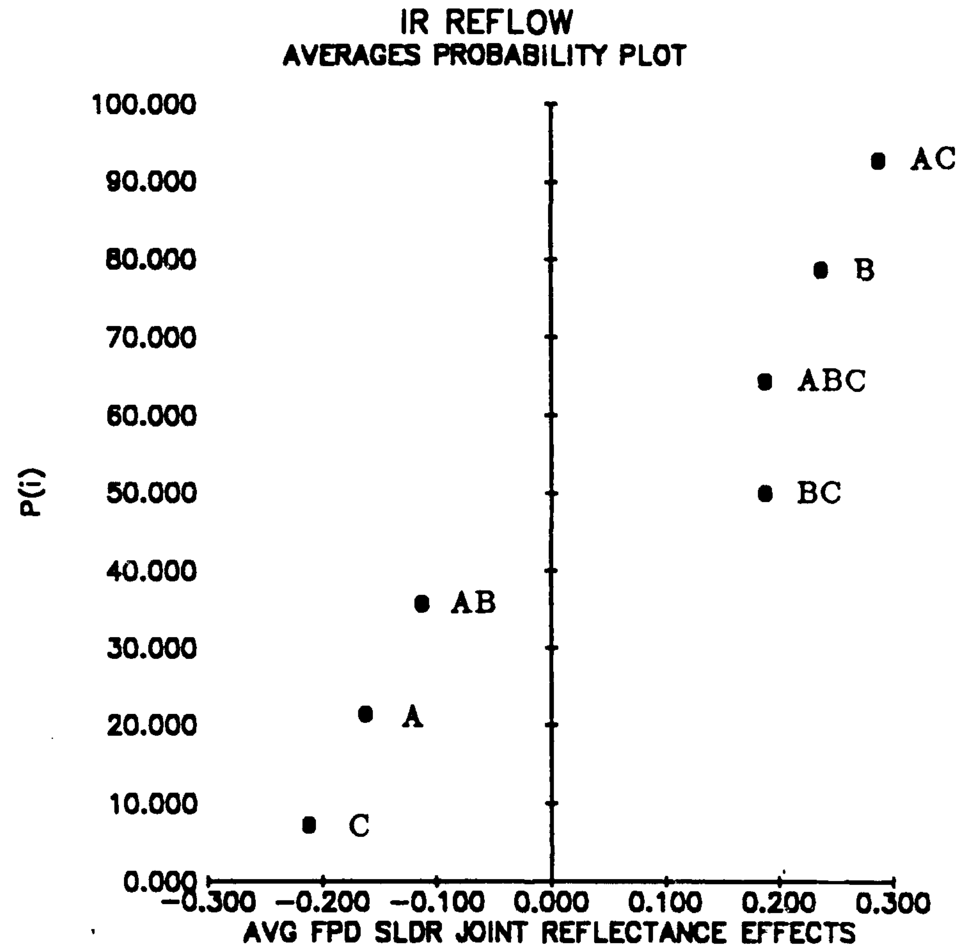

Figure 5. Normal Plot Solder Joint Reflectance Effects, FPDs

Table 3. Interaction Effects Solder Joint Reflectance, FPDs

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	11.15	9.20	10.18	0.98
A	-0.16	0.05	-0.06	-0.11
B	0.24	0.25	0.24	-0.01
C	-0.21	-0.10	-0.16	-0.06
AB	-0.11	-0.10	-0.11	-0.01
AC	0.29	0.15	0.22	0.07
BC	0.19	0.05	0.12	0.07
ABC	0.19	-0.20	-0.01	0.19

Table 4. Effects Table, Normal Design Solder Joint Reflectance, LCCs

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	leveled
1	1.200	1.200	1.200	1.200		1.200		1.200			1.200		1.200		1.200	1.200	
2	1.100	1.400	1.250	1.250		1.250			1.250		1.250	1.250		1.250			1.250
3	1.100	1.200	1.150	1.150			1.150	1.150		1.150			1.150	1.150			1.150
4	1.100	1.100	1.100	1.100			1.100		1.100	1.100		1.100			1.100	1.100	
5	1.100	1.100	1.100		1.100	1.100		1.100		1.100		1.100			1.100		1.100
6	1.600	1.300	1.450		1.450	1.450			1.450	1.450			1.450	1.450		1.450	
7	1.500	1.000	1.250		1.250		1.250	1.250			1.250	1.250		1.250		1.250	
8	1.700	1.100	1.400		1.400		1.400		1.400		1.400		1.400		1.400		1.400
Total			9.90	4.70	5.20	5.00	4.90	4.70	5.20	4.80	5.10	4.70	5.20	5.10	4.80	5.00	4.90
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.238	1.175	1.300	1.250	1.225	1.175	1.300	1.200	1.275	1.175	1.300	1.275	1.200	1.250	1.225
Averages Effect (1<2>-1<1>)				0.125		-0.025		0.125		0.075		0.125		-0.075		-0.025	

Table 5. Effects Table, Folded Design Solder Joint Reflectance, LCCs

Random Order Trial No.:	PWB Serial No.	Resp Obs Values	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	leveled
6	1005	1.70		1.70		1.70		1.70	1.70		1.70		1.70			1.70
4	1011	1.40		1.40		1.40	1.40		1.40			1.40		1.40	1.40	
8	1006	1.30		1.30	1.30			1.30		1.30	1.30			1.30	1.30	
2	1012	1.30		1.30	1.30		1.30			1.30		1.30	1.30			1.30
1	1019	1.40	1.40			1.40		1.40		1.40		1.40	1.40		1.40	
5	1013	1.00	1.00			1.00	1.00			1.00	1.00			1.00		1.00
7	1020	1.10	1.10		1.10			1.10	1.10			1.10		1.10		1.10
3	1014	1.00	1.00		1.00		1.00		1.00		1.00		1.00		1.00	
Total		10.20	4.50	5.70	4.70	5.50	4.70	5.50	5.20	5.00	5.00	5.20	5.40	4.80	5.10	5.10
No. of values		8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average		1.28	1.13	1.43	1.18	1.38	1.18	1.38	1.30	1.25	1.25	1.30	1.35	1.20	1.28	1.28
Std Dev		0.22														
Min		1.00														
Max		1.70														
Effect			0.30		0.20		0.20		-0.05		0.05		-0.15		0.00	

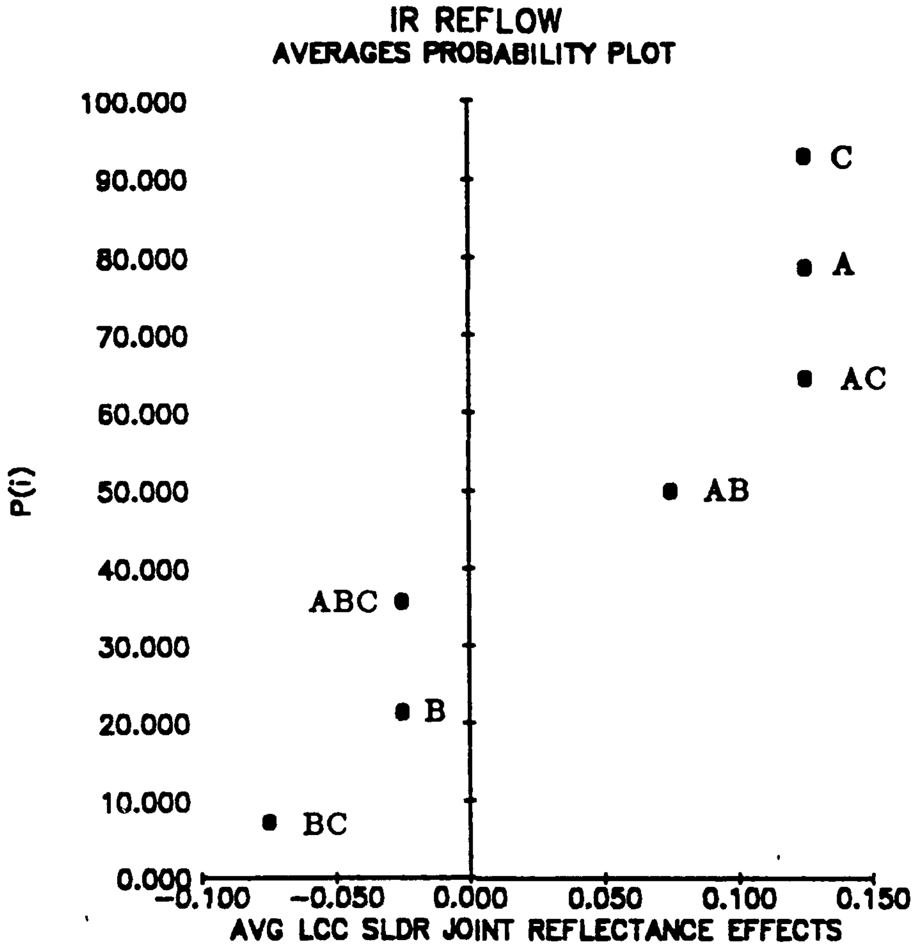

Figure 6. Normal Plot Solder Joint Reflectance Effects, LCCs

Table 6. Interaction Effects Solder Joint Reflectance, LCCs

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	9.90	10.20	10.05	-0.15
A	0.13	0.30	0.21	-0.09
B	-0.03	0.20	0.09	-0.11
C	0.13	0.20	0.16	-0.04
AB	0.08	-0.05	0.01	0.06
AC	0.13	0.05	0.09	0.04
BC	-0.08	-0.15	-0.11	0.04
ABC	-0.03	0.00	-0.01	-0.01

Process variability and the 6 (+/- 3) sigma value needed to calculate the Cpk is found by performing an analysis of variance (ANOVA) of response data from at least two replicate experimental runs. Table 7 presents that analysis for the FPD Solder Joint Reflectance data. Table 8 presents the Cpk and yield data for the FPD Solder Joint Reflectance data. It is a worksheet that uses the 6 sigma value and compares that against the minimum obtained from the process mean minus the lower specification limit times two, and the upper specification limit minus the process mean.

Tables 7 and 8 present the ANOVA and Cpk/yield data for the FPD Solder Joint Reflectance response variable while Tables 9 and 10 do that for the LCC related response.

Table 7. ANOVA Table FPD Solder Joint Reflectance

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	STEN THK	0.052812	1	0.052812	NA	NA	0.0%
2			POWD AGE	0.112812	1	0.112812	2.062	0.22	9.9%
3			LEAD AGE	0.090312	1	0.090312	1.651	0.27	6.1%
4		P	PASTE REG	0.025312	1	0.025312	NA	NA	0.0%
5			PWB AGE	0.165312	1	0.165312	3.022	0.16	18.8%
6		P	COMP REG	0.070312	1	0.070312	NA	NA	0.0%
7		P	PWB STYLE	0.070312	1	0.070312	NA	NA	0.0%
POOLED ERROR:				0.21875	4	0.054687			65.2%
TOTAL(CORRECTED):				0.587187	7				

X(BAR): 1.39 6 SIGMA ----> 1.47

Table 8. Cpk Table FPD Solder Joint Reflectance

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD LEAD, SOLDER JOINT REFLECT, 1-4	1.00	4.00	1.39	1.47

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
0.78	2.04	3.55	10.65

2*(USL-X(BAR))	
5.22	YIELD: 100%, ESSENTIALLY

Table 9. ANOVA Table LCC Solder Joint Reflectance

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			STEN THK	0.03125	1	0.03125	5	0.09	21.1%
2		P	POWD AGE	0.00125	1	0.00125	NA	NA	0.0%
3			LEAD AGE	0.03125	1	0.03125	5	0.09	21.1%
4		P	PASTE REG	0.01125	1	0.01125	NA	NA	0.0%
5			PWB AGE	0.03125	1	0.03125	5	0.09	21.1%
6		P	COMP REG	0.01125	1	0.01125	NA	NA	0.0%
7		P	PWB STYLE	0.00125	1	0.00125	NA	NA	0.0%
POOLED ERROR:				0.025	4	0.00625			36.8%
TOTAL(CORRECTED):				0.11875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 1.24 6 SIG ----> 0.55

Table 10. Cpk Table LCC Solder Joint Reflectance

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
LCC LEAD. SOLDER JOINT REFLECT. 1-4	1.00	4.00	1.24	0.55

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
0.48	5.45	10.04	30.11
2*(USL-X(BAR))			
5.52	YIELD:	100%, ESSENTIALLY	

2.1.1.4 Discussion of Solder Joint Reflectance

FPD Data

Examination of the "effects" data in Table 1 and the pattern of the normal plot in Figure 5 reveals no strong indication that any of the process variables have a strong affect on the reflectance of the FPD solder joint. This trend is supported by the magnitude of the effects found in the folded experiment, Table 2 and the analysis of the possible interactions presented in Table 3.

The ANOVA table for the FPD solder joints, Table 7, has filtered through an indication that the PWB Aging, Component Lead Aging, and Solder Past Aging process variables have an influence on this response variable. It also makes engineering sense that these process variables would impact the visual quality of the solder joints. The Cpk/yield table, Table 8, demonstrates that this process is under control. Additional fine tuning would consider reducing the variability of the significant process variables uncovered by this experiment. The priority for this improvement would not be very high.

LCC Data

Examination of the "effects" data in Table 4 reveals that PWB Aging, Component Lead Aging, and Stencil Thickness process variables have an affect on the reflectance of the LCC solder joint. The normal plot, Figure 6, does not make this very apparent. The interaction analysis, Table 6, indicates that there are no significant interactions, and thus the PWB Aging process variable effect apparently is not confounded with an AC interaction. It is difficult to see how the Stencil Thickness process variable would affect the solder joint reflectance, but this variable is not discounted completely.

The ANOVA table for the LCC solder joints, Table 9, would indicate that the Stencil Thickness, Lead Aging, and PWB Aging process variables are of equal significance. Applying engineering judgment to the results of this analysis would tend to indicate that none of the process variables are having a very significant affect on the reflectance of the LCC solder joint reflectance properties.

Regardless, the Cpk/yield table, Table 10, demonstrates that this process is under control. Additional fine tuning would consider reducing the variability of the significant process variables uncovered by this experiment. The priority for this improvement is not very high.

2.1.2 REFLOWED SOLDER JOINT ROUGHNESS

2.1.2.1 Effects

2.1.2.1.1 Analysis. The effects on the FPD response variable, Solder Joint Roughness, are presented in Tables 11 and 12. Figure 7 is a normal plot of the ranked effects taken from Table 11. Table 13 is the tool that is used to determine whether or not interactions are masking the process variable effects.

Similarly, the effects on the LCC response variable, Solder Joint Roughness, are presented in Tables 14 and 15; and the normal plot of these Table 14 effects are shown in Figure 8. Table 16 is the discriminator between real and interaction effects. A general explanation of response tables, normal plot figures, and interaction tables is presented in paragraph 2.1.1.1.1.

2.1.2.2 ANOVA

2.1.2.3 Capability Indices

Tables 17 and 18 present the ANOVA and Cpk/yield data for the FPD Solder Joint Roughness response variable while Tables 19 and 20 do that for the LCC related response. Paragraph 2.1.1.3 explains the methodology behind the derivation of these tables.

2.1.2.4 Discussion of Solder Joint Roughness

<u>FPD Data</u>

Examination of the "effects" data in Table 11 indicate that only two process variables, Stencil Thickness and PWB Style, do not have a significant affect on the FPD Solder Joint Roughness response variable. In this instance, however, it is not clear how the Component Offset and Paste Deposit Offset process variables would affect the response. The pattern of the normal plot in Figure 7 is inconclusive in that it reveals no strong indication that any of the process variables have a strong affect on the roughness f the FPD solder joint. The magnitude of the effects found in the folded experiment, Table 12, place Paste Offset, PWB Aging, and Component Offset as the significant contributors to the effects on the response variable. Here, as previously noted, the contributions of the two offset process variables to the effects on the response variable need to be discounted. An analysis of the possible interactions presented in Table 13 indicate that interactions among variables are not significant.

The data in the ANOVA table for the FPD solder joints, Table 17, is in agreement with the Effects Table in that only the two process variables, Stencil Thickness and PWB Style give no indication of affecting the FPD Solder Joint Roughness response variable. The Cpk/yield table, Table 18, demonstrates that this process is under control. Additional fine tuning would consider reducing the variability of the process variables that have been indicated to be of possible significance, however, the priority for this improvement would not be very high.

Table 11. Effects Table, Normal Design Solder Joint Roughness, FPDs

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	leveled
1	2.000	2.000	2.000	2.000		2.000		2.000			2.000		2.000		2.000	2.000	
2	1.900	1.000	1.450	1.450		1.450			1.450		1.450	1.450		1.450			1.450
3	2.000	2.100	2.050	2.050			2.050	2.050		2.050			2.050	2.050			2.050
4	2.000	2.000	2.000	2.000			2.000		2.000	2.000		2.000			2.000	2.000	
5	2.000	1.900	1.950		1.950	1.950		1.950		1.950		1.950			1.950		1.950
6	1.800	2.000	1.900		1.900	1.900			1.900	1.900			1.900	1.900		1.900	
7	1.900	1.800	1.850		1.850		1.850	1.850			1.850	1.850		1.850		1.850	
8	2.000	1.900	1.950		1.950		1.950		1.950		1.950		1.950		1.950		1.950
Total			15.15	7.50	7.65	7.30	7.85	7.85	7.30	7.90	7.25	7.25	7.90	7.25	7.90	7.75	7.40
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.894	1.875	1.913	1.825	1.963	1.963	1.825	1.975	1.813	1.813	1.975	1.813	1.975	1.938	1.850
Averages Effect (1<2>-1<1>)				0.037		0.138		-0.138		-0.163		0.163		0.163		-0.087	

Table 12. Effects Table, Folded Design Solder Joint Roughness, FPDs

Random Order Trial No.:	PWB Serial No.	Resp Obs Values	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	le\ led
6	1005	2.00		2.00		2.00		2.00	2.00		2.00		2.00			2.00
4	1011	2.00		2.00		2.00	2.00		2.00			2.00		2.00	2.00	
8	1006	1.70		1.70	1.70			1.70		1.70	1.70			1.70	1.70	
2	1012	2.00		2.00	2.00		2.00			2.00		2.00	2.00			2.00
1	1019	2.00	2.00			2.00		2.00		2.00		2.00	2.00		2.00	
5	1013	1.40	1.40			1.40	1.40			1.40	1.40			1.40		1.40
7	1020	2.00	2.00		2.00			2.00	2.00			2.00		2.00		2.00
3	1014	1.90	1.90		1.90		1.90		1.90		1.90		1.90		1.90	
Total		15.00	7.30	7.70	7.60	7.40	7.30	7.70	7.90	7.10	7.00	8.00	7.90	7.10	7.60	7.40
No. of values		8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average		1.88	1.83	1.93	1.90	1.85	1.83	1.93	1.98	1.78	1.75	2.00	1.98	1.78	1.90	1.85
Effect			0.10		-0.05		0.10		-0.20		0.25		-0.20		-0.05	

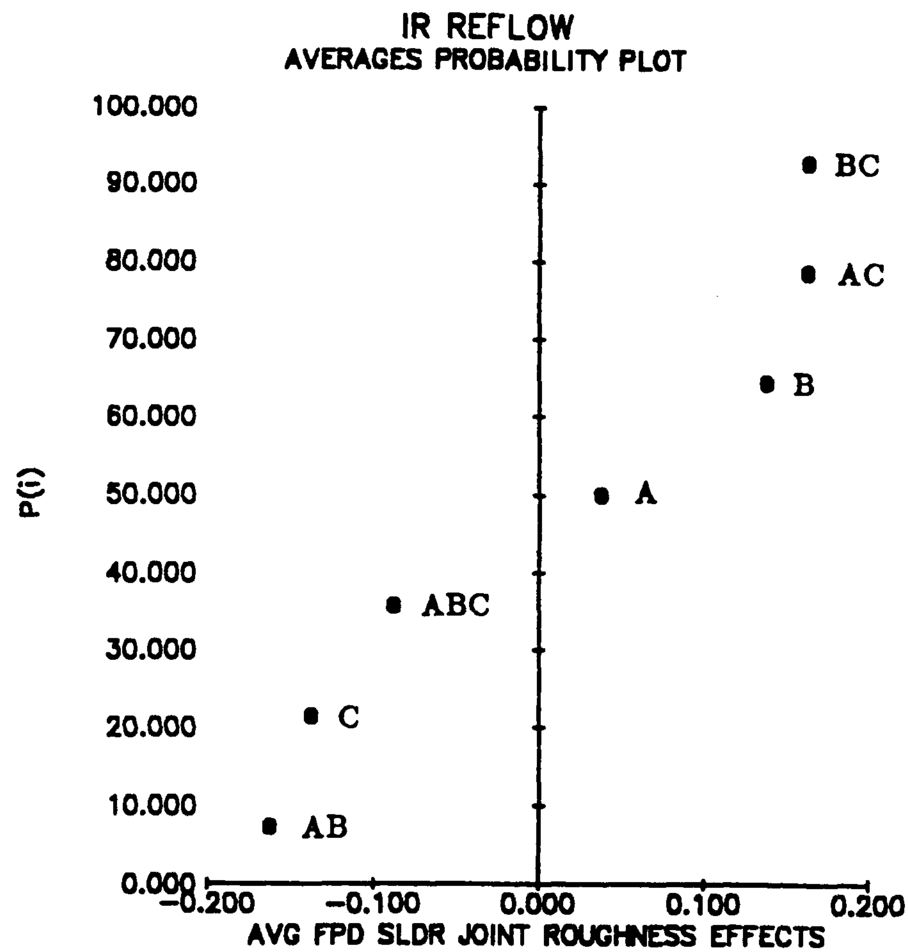

Figure 7. Normal Plot Solder Joint Roughness Effects, FPDs

Table 13. Interaction Effects Solder Joint Roughness, FPDs

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	15.15	15.00	15.08	0.08
A	0.04	0.10	0.07	-0.03
B	0.14	-0.05	0.04	0.09
C	-0.14	0.10	-0.02	-0.12
AB	-0.16	-0.20	-0.18	0.02
AC	0.16	0.25	0.21	-0.04
BC	0.16	-0.20	-0.02	0.18
ABC	-0.09	-0.05	-0.07	-0.02

Table 14. Effects Table, Normal Design Solder Joint Roughness, LCCs

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	leveled
1	1.600	1.600	1.600	1.600		1.600		1.600			1.600		1.600		1.600	1.600	
2	1.600	1.600	1.600	1.600		1.600			1.600		1.600	1.600		1.600			1.600
3	1.600	1.800	1.700	1.700			1.700	1.700		1.700			1.700	1.700			1.700
4	1.800	1.200	1.500	1.500			1.500		1.500	1.500		1.500			1.500	1.500	
5	1.600	1.300	1.450		1.450	1.450		1.450		1.450		1.450			1.450		1.450
6	2.000	1.600	1.800		1.800	1.800			1.800	1.800			1.800	1.800		1.800	
7	1.700	1.200	1.450		1.450		1.450	1.450			1.450	1.450		1.450		1.450	
8	1.800	1.500	1.650		1.650		1.650		1.650		1.650		1.650		1.650		1.650
Total			12.75	6.40	6.35	6.45	6.38	6.20	6.55	6.45	6.30	6.00	6.75	6.55	6.20	6.35	6.40
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.594	1.600	1.588	1.613	1.575	1.550	1.638	1.613	1.575	1.500	1.688	1.638	1.550	1.588	1.600
Averages Effect (1(2)-1(1))				-0.013		-0.037		0.088		-0.037		0.188		-0.087		0.013	

Table 15. Effects Table, Folded Design Solder Joint Roughness, LCCs

Random Order Trial No.	PWB Serial No.	Resp Obs Values	A Stencil Thickness, mils 4/10	10/14	B Powder Aging, hours/95C 0	24	C Lead Steam Aging, hours 0	8	AB Paste Deposit Offset, mils 0/0	-3/-3	AC PWB Lead Steam Aging, hours 0	8	BC Component Offset, mils 0/0	3/3	ABC PWB Style fused	leveled
6	1005	2.00		2.00		2.00		2.00	2.00		2.00		2.00			2.00
4	1011	1.80		1.80		1.80	1.80		1.80			1.80		1.80	1.80	
8	1006	1.90		1.90	1.90			1.90		1.90	1.90			1.90	1.90	
2	1012	1.90		1.90	1.90		1.90			1.90		1.90	1.90			1.90
1	1019	1.80	1.80			1.80		1.80		1.80		1.80	1.80		1.80	
5	1013	1.30	1.30			1.30	1.30			1.30	1.30			1.30		1.30
7	1020	1.40	1.40		1.40			1.40	1.40			1.40		1.40		1.40
3	1014	1.00	1.00		1.00		1.00		1.00		1.00		1.00		1.00	
Total		13.10	5.50	7.60	6.20	6.90	6.00	7.10	6.20	6.90	6.20	6.90	6.70	6.40	6.50	6.60
No. of values		8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average		1.64	1.38	1.90	1.55	1.73	1.50	1.78	1.55	1.73	1.55	1.73	1.68	1.60	1.63	1.65
Effect			0.53		0.18		0.28		0.18		0.18		-0.08		0.02	

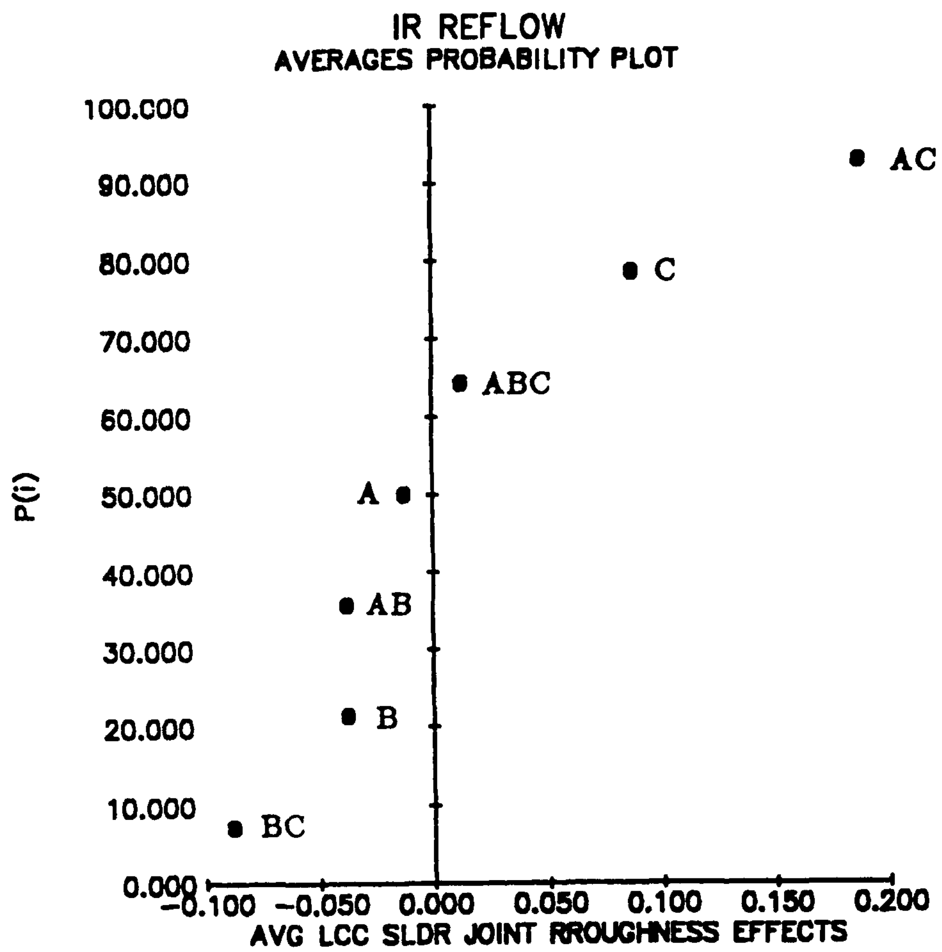

Figure 8. Normal Plot Solder Joint Roughness Effects, LCCs

Table 16. Interaction Effects Solder Joint Roughness, LCCs

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	12.75	13.10	12.93	-0.18
A	-0.01	0.53	0.26	-0.27
B	-0.04	0.18	0.07	-0.11
C	0.09	0.28	0.18	-0.10
AB	-0.04	0.18	0.07	-0.11
AC	0.19	0.18	0.18	0.00
BC	-0.09	-0.08	-0.08	0.00
ABC	0.01	0.02	0.02	0.00

Table 17. ANOVA Table FPD Solder Joint Roughness

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	STEN THK	0.002812	1	0.002812	NA	NA	0.0%
2			POWD AGE	0.037812	1	0.037812	4.172	0.18	11.4%
3			LEAD AGE	0.037812	1	0.037812	4.172	0.18	11.4%
4			PASTE REG	0.052812	1	0.052812	5.827	0.14	17.3%
5			PWB AGE	0.052812	1	0.052812	5.827	0.14	17.3%
6			COMP REG	0.052812	1	0.052812	5.827	0.14	17.3%
7		P	PWB STYLE	0.015312	1	0.015312	NA	NA	0.0%
POOLED ERROR:				0.018125	2	0.009062			25.2%
TOTAL(CORRECTED):				0.252187	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 1.89 6 SIGMA ----> 0.72

Table 18. Cpk Table FPD Solder Joint Roughness

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD LEAD, SOLDER JOINT ROUGHNESS 1-4	1.00	4.00	1.89	0.72

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
1.78	4.17	5.86	17.58

2*(USL-X(BAR))

4.22

YIELD: 100%, ESSENTIALLY

Table 19. ANOVA Table LCC Solder Joint Roughness

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	STEN THK	0.000312	1	0.000312	NA	NA	0.0%
2		P	POWD AGE	0.002812	1	0.002812	NA	NA	0.0%
3		P	LEAD AGE	0.015312	1	0.015312	NA	NA	0.0%
4		P	PASTE REG	0.002812	1	0.002812	NA	NA	0.0%
5			PWB AGE	0.070312	1	0.070312	11.44	0.01	59.9%
6		P	COMP REG	0.015312	1	0.015312	NA	NA	0.0%
7		P	PWB STYLE	0.000312	1	0.000312	NA	NA	0.0%
POOLED ERROR:				0.036875	6	0.006145			40.1%
TOTAL(CORRECTED):				0.107187	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 1.59 6 SIGMA ----> 0.53

Table 20. Cpk Table LCC Solder Joint Roughness

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD LEAD, SOLDER JOINT ROUGHNESS 1-4	1.00	4.00	1.59	0.53

	CP	CPK	PROCESS SIGMA
2*(X(BAR)-LSL)			
1.18	5.66	9.09	27.28
2*(USL-X(BAR))			
4.82	YIELD:	100%, ESSENTIALLY	

LCC Data

Examination of the "effects" data in Table 14 reveals that PWB Aging, Component Lead Aging, and Component Offset process variables have an affect on the roughness of the LCC solder joint. The normal plot, Figure 8, backs up this observation. The interaction analysis, Table 16, indicates that there are no significant interactions, and thus the PWB Aging process variable effect apparently is not confounded with an AC interaction. It is difficult to see how the Component Offset process variable would affect the solder joint roughness. Engineering judgment would indicate that this variable should be discounted.

The ANOVA table for the LCC solder joints, Table 19, would indicate that only the PWB Aging process variable is of significance. It is curious that the ANOVA would contrast so much with the effect table. A lesson learned might be that all analysis tools should be utilized in efforts to uncover significant process variables. Regardless, the Cpk/yield table, Table 20, demonstrates that this process is under control. Additional fine tuning would consider reducing the variability of the significant process variables uncovered by this experiment, however, the priority for working on this improvement is not very high.

2.1.3 Component Solder Joint Temperature Versus PWB Thickness

2.1.3.1 Effects

2.1.3.1.1 Analysis. A single point experiment was designed to determine the effect of PWB thickness on the temperature of component solder joints as the PWB courses its way through the infrared reflow oven. All process variables, such as heater panel temperatures and conveyor belt speed were held constant throughout this experiment. The details are presented in Appendix B to this report. The PWB thickness was varied over a 10-mil range to duplicate the variation allowed by TRW MEAD design documentation. After solder pasting two of the minimum thickness PWPs and two of the maximum thickness PWBs, the four PWAs were infrared reflowed (refer to Figure 10). Five thermocouples (chromel-alumel) were mounted to each of the four PWAs in such a manner that the thermocouple beads were in intimate contact with select solder joints. (See Figure 9.) Each PWA was run through the infrared oven twice. A Mole was connected to the thermocouples so that temperatures could be gathered as the PWA passed through the oven. Just prior to entering the infrared oven, the ambient temperature of a solder joint was measured. The data from the Mole was dumped to a software program which documented the temperature profiles of each of the five thermocouples attached to the PWA under test. Table 21 lists the temperatures gathered from the experiment for analysis. The thermocouple temperature

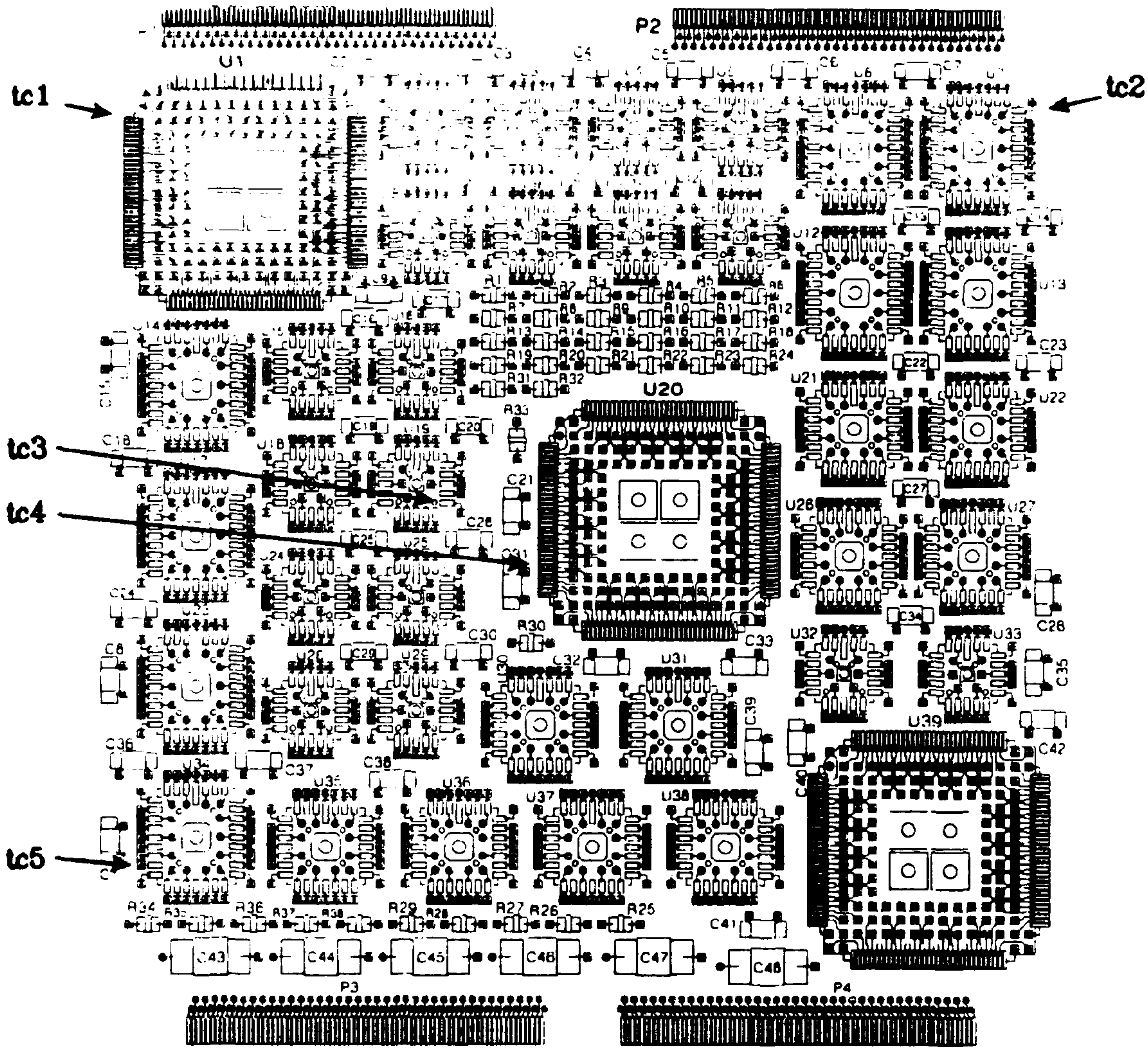

Figure 9. EMPI PWB Showing Thermocouple Bead Locations

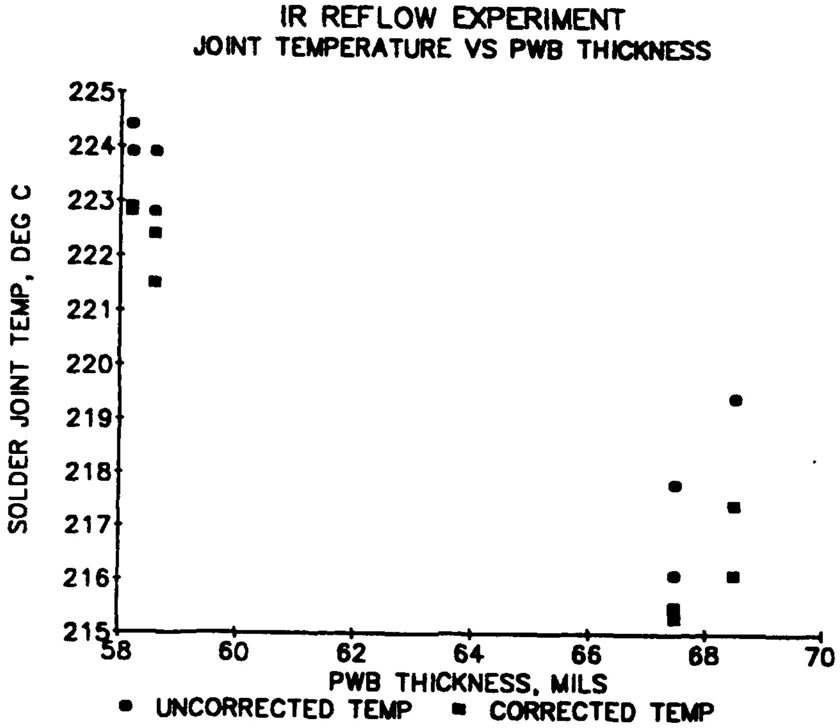

Figure 10. Plot of PWB Thickness Versus Corrected and Uncorrected Solder Joint Temperatures

Table 21. Collected Data for PWB Thickness Versus Solder Joint Temperature

NITROGEN IS 'ON' IN ALL CASES

PWB SN	PWB THICKNESS MILS	INITIAL TEMP DEG C	UNCORRECTED TEMPERATURE DEG C	CORRECTED TEMPERATURE DEG C	HOLE FILE NAME
1025	68.5	24.1	216.1	216.1	29
1026	67.5	24.9	216.1	215.3	30
1027	58.6	24.5	222.8	222.4	31
1028	58.2	25.1	223.9	222.9	32
1025	68.5	26.1	219.4	217.4	33
1026	67.5	26.4	217.8	215.5	34
1027	58.6	26.5	223.9	221.5	35
1028	58.2	25.7	224.4	222.8	36
min	58.2			215.3	
max	68.5			222.9	
delta	10.3			7.6	
avg	63.2			219.2	
std dev	4.8			3.2	

reported was the minimum of the five thermocouples at the peak temperature condition for that thermocouple. The corrected temperature is a normalization to he minimum recorded ambient temperature noted just prior to entering into the infrared reflow oven. In this experiment, that normalization temperature is 24.1°C. Table 22 is a worksheet that is used to compute the least squares fit of the data gathered from this experiment. The equation derived from the least squares analysis of the corrected temperature recordings was calculated to be:

$$y = 260.28 - 0.65 * x$$

Table 21a. Least Squares Curve Fitting for PWB Thickness Versus Solder Joint Temperature

LEAST SQUARES CURVE FITTING

N	X	Y	X^2	XY	Y^2
8	68.5	216.1	4692.25	14802.85	46699.21
	67.5	215.3	4556.25	14532.75	46354.09
	58.6	222.4	3433.96	13032.64	49461.76
	58.2	222.9	3387.24	12972.78	49684.41
	68.5	217.4	4692.25	14891.9	47262.76
	67.5	215.5	4556.25	14546.25	46440.25
	58.6	221.5	3433.96	12979.9	49062.25
	58.2	222.8	3387.24	12966.96	49639.84
SUMS	505.6	1753.9	32139.4	110726.03	384604.57

a0	a1	Y=
260.28	-0.65	260.28-.65*X

Where Y=solder joint temp, deg c
and X=PWB thickness, mils

Where the thickness range can be 10 mils, the solder joint temperature can range over 6.5°C. The significance of this number is that MIL-STD-2000 requires that the temperature of machine soldered solder joints stay within a plus or minus 5°C range from run to run. The target temperature of the soldering process is more or less left up to me vendor; it is the variation that is controlled by the specification.

Since the variability of the process is to be controlled and not the target value, Cp can be used to measure the process. This is the only instance in this study where that situation exists. The Cp is equal to the specification range (+5 °C to -5°C) 10°C divided by the standard deviation of the gathered data. From Table 21 that standard deviation is shown tc be 3.2. Therefore,

$$Cp = (10°C)/(3.2°C) = 3.1875$$

2.1.4 Final Run Process Variables

Based on the results of this phase of the EMPI for PWA program, the following process parameters will be controlled for the infrared reflow process: (1) the 210°C infrared reflow profile will be used; (2) neither the components nor the PWBs will be steam aged; and (3) a nitrogen environment will be used inside the infrared oven.

Both fused and hot air leveled finished PWBs and Metech and Multicore solder pastes will be two-level process variables, because the combination of pastes and PWB finishes were never examined in the previous experiments.

2.2 SUBTASK 2, FINE PITCH DEVICE LEAD TINNING

The details of the fine pitch device (FPD) lead tinning experiment are presented in Appendix C to this report. The thrust of the experiment is presented in Figure 11. All of the response data for all of the responses have been collected and reduced and are presented in this report.

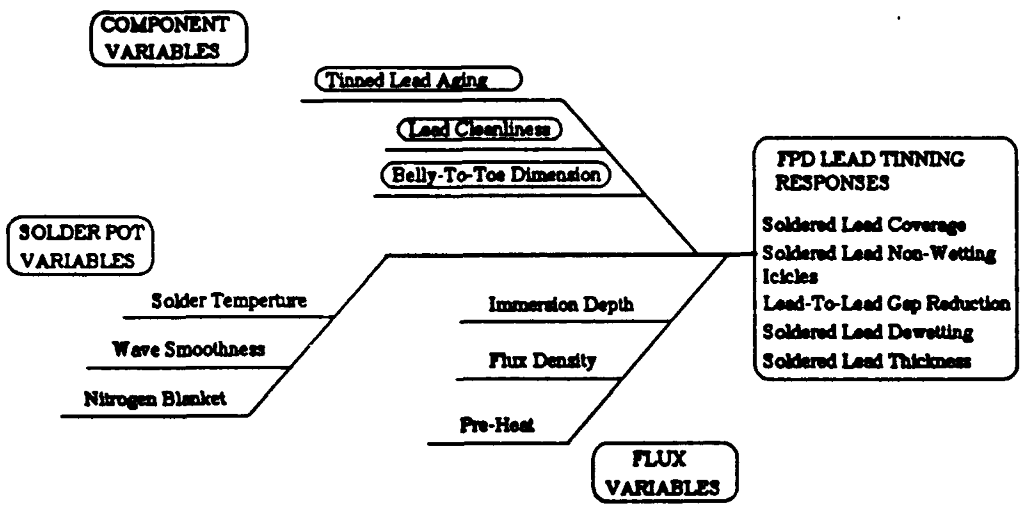

Figure 11. Fine Pitch Device Lead Tinning
Subtask Cause and Effect Diagram

This subtask involved two eight-run experiments in three process variables. The second experiment was a replicate of the first and was used to determine the variability of the process in addition to the process mean. Since this was a full-factorial design, no reflected runs were required to identify possible interactions between process variables that might have masked assigned process variable effects.

2.2.1 Fine Pitch Device Lead Solder Coverage

2.2.1.1 Effects

2.2.1.1.1 Analysis. The effects of the three process variables on the response variable, Solder Coverage, are presented in Table 22. Figure 12 is a normal plot of the ranked effects taken from Table 22. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.2.1.2 ANOVA

2.2.1.3 Capability Indices

Tables 23 and 24 present the ANOVA and Cpk/yield data, respectively, for the FPD Lead Solder Coverage response variable. Paragraph 1.1.3 explains the methodology behind the derivation of these types of tables.

Table 22. Effects Table, Normal Design FPD Lead Solder Coverage

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Belly-To-Toe Dim, mils 4	12	B Lead Aging, months 0	12	C Lead Cleanliness clean	contam	AB *************	INTERACTION	AC AND	ERROR	BC TERMS	*************	ABC	
1	91.670	93.000	92.335	92.335		92.335		92.335			92.335		92.335		92.335	92.335	
2	90.110	87.190	88.650	88.650		88.650			88.650		88.650	88.650		88.650			88.650
3	57.720	72.750	65.235	65.235			65.235	65.235		65.235			65.235	65.235			65.235
4	71.690	59.720	65.705	65.705			65.705		65.705	65.705		65.705			65.705	65.705	
5	93.810	77.220	85.515		85.515	85.515		85.515		85.515		85.515			85.515		85.515
6	98.080	91.500	94.790		94.790	94.790			94.790	94.790			94.790	94.790		94.790	
7	77.280	68.830	73.055		73.055		73.055	73.055			73.055	73.055		73.055		73.055	
8	93.220	63.940	78.580		78.580		78.580		78.580		78.580		78.580		78.580		78.580
Total			643.87	311.93	331.94	361.29	282.58	316.14	327.73	311.25	332.62	312.93	330.94	321.73	322.14	325.89	317.98
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			80.483	77.981	82.985	90.323	70.644	79.035	81.931	77.811	83.155	78.231	82.735	80.433	80.534	81.471	79.495
Averages Effect (1<2>-1<1>)				5.004		-19.679		2.896		5.344		4.504		0.101		-1.976	

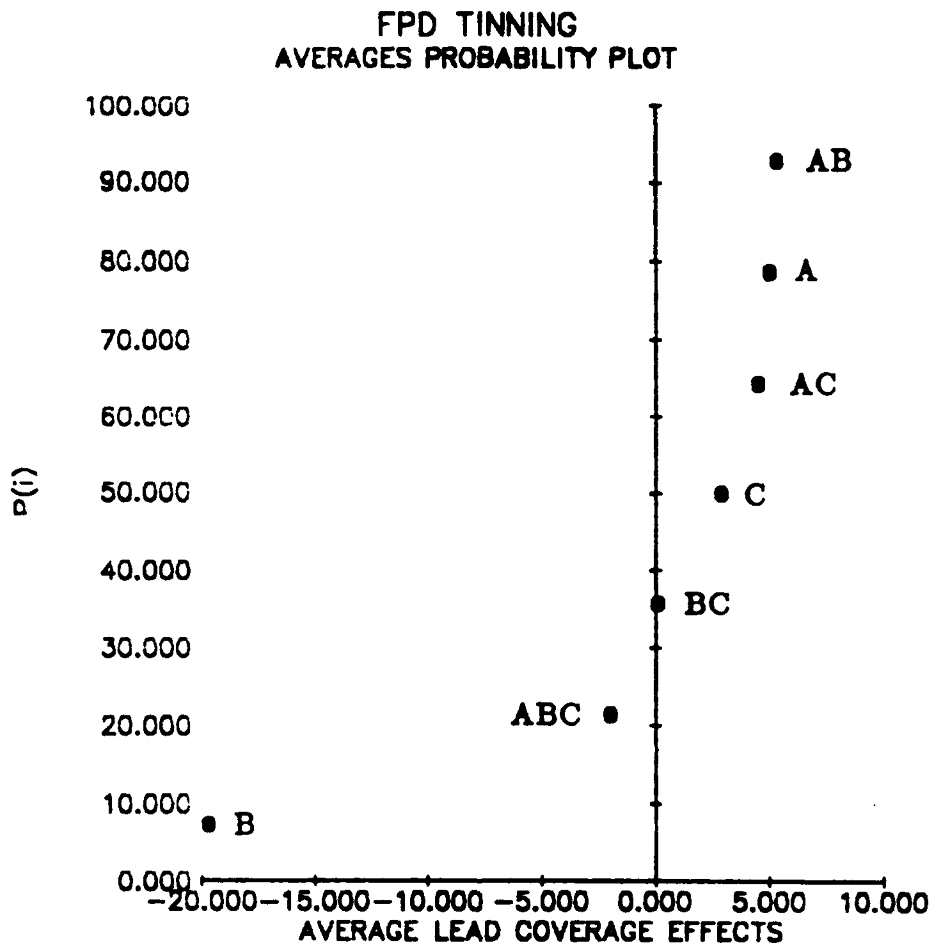

Figure 12. Normal Plot FPD Lead Solder Coverage Effects

Table 23. ANOVA Table FPD Lead Solder Coverage

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			BL-TO-TOE	98.21011	1	98.21011	10.84	0.02	8.2%
2			LEAD AGE	940.2616	1	940.2616	103.8	0.00	85.9%
3		P	LEAD CLN	1.593112	1	1.593112	NA	NA	0.0%
4		P	ERROR	22.3112	1	22.3112	NA	NA	0.0%
5		P	ERROR	12.5	1	12.5	NA	NA	0.0%
6		P	ERROR	8.86205	1	8.86205	NA	NA	0.0%
7		P	ERROR	0.001512	1	0.001512	NA	NA	0.0%
POOLED ERROR:				45.26787	5	9.053575			5.8%
TOTAL(CORRECTED):				1083.739	7				

X(BAR): 81.485 6 SIGMA ----> 36.69

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

Table 24. Cpk Table FPD Lead Solder Coverage

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD LEAD, SOLDER COVERAGE, % 25-100	25.00	100.00	81.48	36.69

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
112.96	2.04	1.01	3.03

2*(USL-X(BAR))

37.04

YIELD: 99.76%

2.2.1.4 Discussion of FPD Lead Solder Coverage

Unlike the situation with the infrared reflow experiment, an examination of the solder coverage "effects" data in Table 22 indicate that FPD lead aging has a very strong effect on the solder coverage of FPD leads. As might be expected, aging has an adverse affect on solder coverage; that is, aging causes less solder coverage.

A surprise here is that the Lead Cleanliness process variable has no significant affect on the response. Engineering judgment here would have suggested just the opposite. That is it was anticipated that lack of lead cleanliness would have resulted in minimum lead solder coverage. This experiment shows conclusively that for the TRW MEAD robotic FPD lead tinning process, leads contaminated with hydrocarbon oils do not adversely affect the lead tinning response of solder coverage.

The belly-to-toe dimension process variable was included because it was thought that this parameter could affect the depth that the robot inserted the component leads into the solder pot. The negligible effect found eliminates the need to take special precautions to control this variable.

The pattern of the normal plot in Figure 12 supports the effects data. The lower left data point, associated with the Lead Aging variable, falls significantly to the left of an imaginary straight line drawn through the remaining points. This is the condition that allows one to conclude that the effect represented by that point is not one that might be expected if the effect were due only to normal variation. Although the other points on this figure do not exactly fit a straight line, their deviation is not significant.

The data in the ANOVA table for the FPD lead solder coverage, Table 23 is in agreement with the data in the effects table. Lead aging accounts for about 86 percent of the variability encountered in the solder coverage response. Here, the belly-to-toe variable shows some significance that is slightly higher than the pooled noise figure. This effect needs to be kept in mind, but it is not of any immediate concern.

The Cpk/yield table, Table 24, demonstrates that this process is under control with the Cpk value just above 1. A significant improvement could be achieved by lowering the mean value of the process which is now at about 81 percent. Changes to MIL-STD-2000 have reduced the pressure to do this, because it permits a larger upper specification limit which would, by default, increase the Cpk without doing anything to this process.

2.2.2 Fine Pitch Device Tinned Lead Solder Non-Wetting, Dewetting, and Icicling

2.2.2.1 Effects

2.2.2.1.1 Analysis. The effects on the response variables, FPD Tinned Lead Non-Wetting, FPD Tinned Lead Dewetting, and FPD Tinned Lead Icicling are not presented in tabular form; because no evidence of tinned lead non-wetting, dewetting nor icicling was observed on any of the 16 samples of fine pitch devices evaluated in these two experiments.

2.2.2.2 ANOVA

ANOVA is not warranted when no variability is discovered or measured.

2.2.2.3 Capability Indices

Capability indices are infinite for all practical purposes, and the yields for these process responses are essentially 100 percent.

2.2.2.4 Discussion of FPD Tinned Lead Non-wetting, dewetting, and Icicling

Clearly, the non-wetting, dewetting, and icicling response variables for this experiment need no further attention. Any problems encountered in the future would suggest that the process variables used for this experiment be checked to see if they exceed their specification limits. If they do, they must be brought into the range required. If they do not exceed the acceptable process limits, then the problem lies somewhere outside of the process variables tested here. This knowledge will reduce the time required to troubleshoot process problems by eliminating the need to revisit some of the potential causes of the problems.

2.2.3 Fine Pitch Device Lead-to-Lead Gap Reduction

2.2.3.1 Effects

2.2.3.1.1 Analysis. The effects of the three process variables on the response variable, FPD Tinned Lead-to-Lead Gap Reduction, are presented in Table 25. Figure 13 is a normal plot of the ranked effects taken from Table 25. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.2.3.2 ANOVA

2.2.3.3 Capability Indices

Tables 25 and 26 present the ANOVA and Cpk/yield data, respectively, for the FPD Tinned Lead-to-Lead Gap Reduction response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.2.3.4 Discussion of FPD Tinned Lead-to-Lead Gap Reduction

An examination of the solder coverage "effects" data in Table 25 indicates that: (1) the magnitude of the largest effect on the response variable is quite small (-0.143) in relation to the specification limit for the response variable (10 mils) and (2) there are no effects that stand out as significant contributors.

The pattern of the normal plot in Figure 13 supports the effects data. None of the data points at the lower end of the plot deviate to the left of an imaginary straight line drawn through the points in the center of the line. none of the data points at the upper end of the plot deviate to the right. The message here is that the position of all of the points can be explained by a normal distribution of the points, and none of the process variables are significant.

Table 25. Effects Table, Normal Design FPD Tinned Lead, Lead-to-Lead Gap Reduction

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Belly-To-Toe Dim, mils 4	12	B Lead Aging, months 0	12	C Lead Cleanliness clean	contam	AB		AC		BC		ABC	
										**************	INTERACTION	AND	ERROR	TERMS		**************	
1	0.590	0.820	0.705	0.705		0.705		0.705			0.705		0.705		0.705	0.705	
2	0.720	0.790	0.755	0.755		0.755			0.755		0.755	0.755		0.755			0.755
3	0.840	0.390	0.615	0.615			0.615	0.615		0.615			0.615	0.615			0.615
4	0.390	0.690	0.540	0.540			0.540		0.540	0.540		0.540			0.540	0.540	
5	0.690	0.840	0.765		0.765	0.765		0.765		0.765		0.765			0.765		0.765
6	0.720	0.390	0.555		0.555	0.555			0.555	0.555			0.555	0.555		0.555	
7	1.070	0.740	0.905		0.905		0.905	0.905			0.905	0.905		0.905		0.905	
8	0.520	0.620	0.570		0.570		0.570		0.570		0.570		0.570		0.570		0.570
Total			5.41	2.62	2.80	2.78	2.63	2.99	2.42	2.48	2.94	2.97	2.45	2.83	2.58	2.71	2.71
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			0.676	0.654	0.699	0.695	0.658	0.748	0.605	0.619	0.734	0.741	0.611	0.708	0.645	0.676	0.676
Averages Effect (1<2>-1<1>)				0.045		-0.037		-0.143		0.115		-0.130		-0.063		0.000	

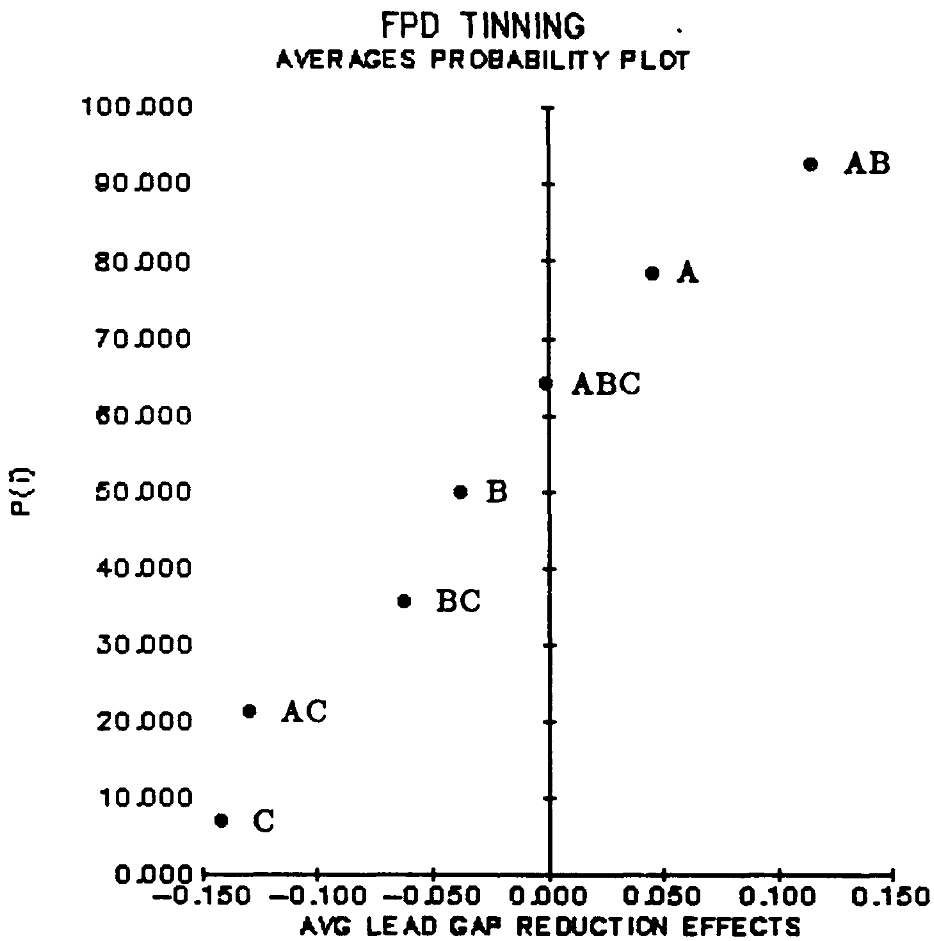

Figure 13. Normal Plot FPD Tinned Lead
Lead-to-Lead Gap Reduction

Table 26. ANOVA Table FPD Tinned
Lead-to-Lead Gap Reduction

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	BL-TO-TOE	0.00405	1	0.00405	NA	NA	0.0%
2		P	LEAD AGE	0.002812	1	0.002812	NA	NA	0.0%
3			LEAD CLN	0.040612	1	0.040612	11.06	0.03	32.0%
4			ERROR	0.02645	1	0.02645	7.209	0.05	19.7%
5			ERROR	0.0338	1	0.0338	9.212	0.04	26.1%
6		P	ERROR	0.007812	1	0.007812	NA	NA	0.0%
7		P	ERROR	0	1	0	NA	NA	0.0%
POOLED ERROR:				0.014675	4	0.003668			22.2%
TOTAL(CORRECTED):				0.115537	7				

X(BAR): 0.67625 6 SIGMA ----> 0.47

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

The data in the ANOVA table for the FPD lead-to-lead gap reduction, Table 26, is not in complete agreement with either the effects table or the normal plot of the associated effects. This table indicates that the Lead Cleanliness process variable has a mildly significant influence on the response variable. It needs to be noted, however, that the significance of this influence is greater than that assigned to two interaction effects (AB and AC). Since factor A (belly-to-toe dimension) has no significance, one is tempted to say that there are probably no interaction affects between it and another factor (process variable).

All of this discussion may seem to be academic since the Cpk/yield table, Table 27, demonstrates that this process is under control with an enormous Cpk value of 39.68. This size number certainly is an indicator of an extremely robust process which is the ultimate goal for any manufacturing operation.

Table 27. Cpk Table FPD Tinned Lead Lead-to-Lead Gap Reduction

RESP VAR	SPEC LIMIT LOWER	SPEC LIMIT UPPER	X(BAR)	6 SIGMA(total) TERM
FPD LEAD. GAP REDUCTION 0-10	0.00	10.00	0.68	0.47

	CP	CPK	PROCESS SIGMA
2*(X(BAR)-LSL): 1.35			
	21.28	39.68	119.03
2*(USL-X(BAR)): 18.65			

YIELD: 100%, ESSENTIALLY

2.2.4 Fine Pitch Device Lead Solder Thickness

2.2.4.1 Effects

2.2.4.1.1 Analysis. The effects of the three process variables on the response variable, FPD Tinned Lead Solder Thickness are presented in Table 28. Figure 14 is a normal plot of the ranked effects taken from Table 28. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.2.4.2 ANOVA

2.2.4.3 Capability Indices

Tables 29 and 30 present the ANOVA and Cpk/yield data, respectively, for the FPD Tinned Lead Solder Thickness Gap response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.2.4.4 Discussion of FPD Tinned Lead Solder Thickness

As was the case with the lead gap-to-gap reduction response, an examination of the solder coverage "effects" data in Table 28 also indicates that: (1) the magnitude of the largest effect on the response variable is quite small (0.056) in relation to the specification limit for the response variable (1 mil) and (2) there are no effects that stand out as significant contributors. Although the magnitude of the effect is less, its value relative to the specification limits (0.9 mil) is greater than that encountered in the previous analysis for gap reduction.

The pattern of the normal plot in Figure 14 supports the effects data. None of the data points at the lower end of the plot deviate to the left of an imaginary straight line drawn through the points in the center of the line. None of the data points at the upper end of the plot deviate to the right. Again, the message here is that the position of all of the points can be explained by a normal distribution of the points, and thus none of the process variables are statistically significant.

The data in the ANOVA table for the FPD lead-to-lead gap reduction, Table 29, is not in complete agreement with either the effects table or the normal plot of the associated effects. This table indicates that the belly-to-toe process variable has a statistically significant influence on the response variable. This significance cannot be explained away.

The Cpk/yield table, Table 30, demonstrates that this process is under control with a large Cpk value of 4.59. This size number certainly is an indicator of an extremely robust process which is the ultimate goal for any manufacturing operation. Nevertheless, variability can be reduced by tending toward the minimum side of the belly-to-toe dimension. This must be balanced off against the increased difficulty of cleaning under the FPD package when the gap between the package and the PWB is reduced. The belly-to-toe dimension is the measure for that gap.

Table 28. Effects Table, Normal Design FPD Tinned Lead Solder Thickness

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Belly-To-Toe		Lead		Lead									
Trial	Variables			Dim, mils		Aging,	months	Cleanliness		**************	INTERACTION	AND	ERROR	TERMS		**************	
No.	Normal	Replic	Avg.	4	12	0	12	clean	contam								
1	0.650	0.720	0.685	0.685		0.685		0.685			0.685		0.685		0.685	0.685	
2	0.630	0.640	0.635	0.635		0.635			0.635		0.635	0.635		0.635			0.635
3	0.720	0.660	0.690	0.690			0.690	0.690		0.690			0.690	0.690			0.690
4	0.680	0.690	0.685	0.685			0.685		0.685	0.685		0.685			0.685	0.685	
5	0.750	0.760	0.755		0.755	0.755		0.755		0.755		0.755			0.755		0.755
6	0.690	0.680	0.685		0.685	0.685			0.685	0.685			0.685	0.685		0.685	
7	0.780	0.660	0.720		0.720		0.720	0.720			0.720	0.720		0.720		0.720	
8	0.780	0.740	0.760		0.760		0.760		0.760		0.760		0.760		0.760		0.760
Total			5.62	2.70	2.92	2.76	2.85	2.85	2.77	2.82	2.80	2.80	2.82	2.73	2.89	2.78	2.84
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			0.702	0.674	0.730	0.690	0.714	0.713	0.691	0.704	0.700	0.699	0.705	0.683	0.721	0.694	0.710
Averages Effect (1<2>-1<1>)				0.056		0.024		-0.021		-0.004		0.006		0.039		0.016	

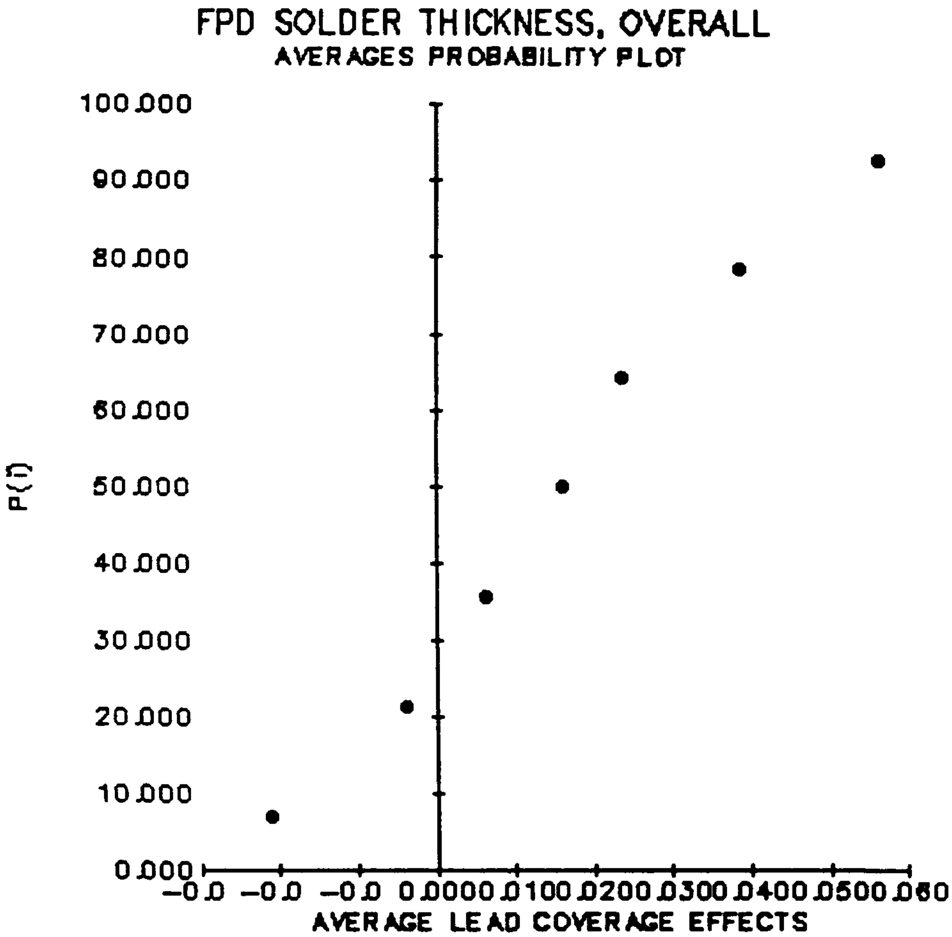

Figure 14. Normal Plot FPD Tinned Lead Solder Thickness

Table 29. ANOVA Table FPD Tinned Lead Solder Thickness

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			BL-TO-TOE	0.006328	1	0.006328	29.92	0.01	51.0%
2			LEAD AGE	0.001128	1	0.001128	5.334	0.10	7.6%
3			LEAD CLN	0.000903	1	0.000903	4.270	0.13	5.8%
4		P	ERROR	0.000028	1	0.000028	NA	NA	0.0%
5		P	ERROR	0.000078	1	0.000078	NA	NA	0.0%
6			ERROR	0.003003	1	0.003003	14.20	0.03	23.3%
7		P	ERROR	0.000528	1	0.000528	NA	NA	0.0%
POOLED ERROR:				0.000634	3	0.000211			12.3%
TOTAL(CORRECTED):				0.011996	7				

X(BAR): 0.701875 6 SIGMA ----> 0.13

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

Table 30. Cpk Table FPD Tinned Lead Solder Thickness

RESP VAR	SPEC LIMIT LOWER	SPEC LIMIT UPPER	X(BAR)	6 SIGMA(total) TERM
TINNED LEAD SLDR THICKNESS .1-1	0.10	1.00	0.70	0.13

	CP	CPK	PROCESS SIGMA
2*(X(BAR)-LSL): 1.20			
	6.92	4.59	13.76
2*(USL-X(BAR)): 0.60			

YIELD: 100%, ESSENTIALLY

2.2.5 Final Run Process Variables

Based on the results of this phase of the EMPI for PWAs program, the process parameters for this FPD Lead Tinning subtask will be modified. The belly-to-toe dimension will be set to 5 to 7 mil from 4 mil to 6 mil. As will be seen in the cleaning experiment (subtask 3), the need to be able to clean underneath the FPD component after infrared reflow soldering outweighs the need to make the solder thickness more robust and the need to improve the centering for the solder coverage response. Because of the significant affect that lead aging showed on solder coverage, this process variable will be brought under tighter limits to reduce the process variability. FPD packages will be stored in an environmentally controlled area, and the shelf life of the package will be controlled to a maximum of 6 months after receipt.

2.3 SUBTASK 3

2.3.1 Subtask 3, Experiment 1, Component Standoff

The details of the component standoff experiment are presented in Appendix D. The thrust of the experiment is presented in Figure 15, Component Standoff Subtask Cause and Effect Diagram.

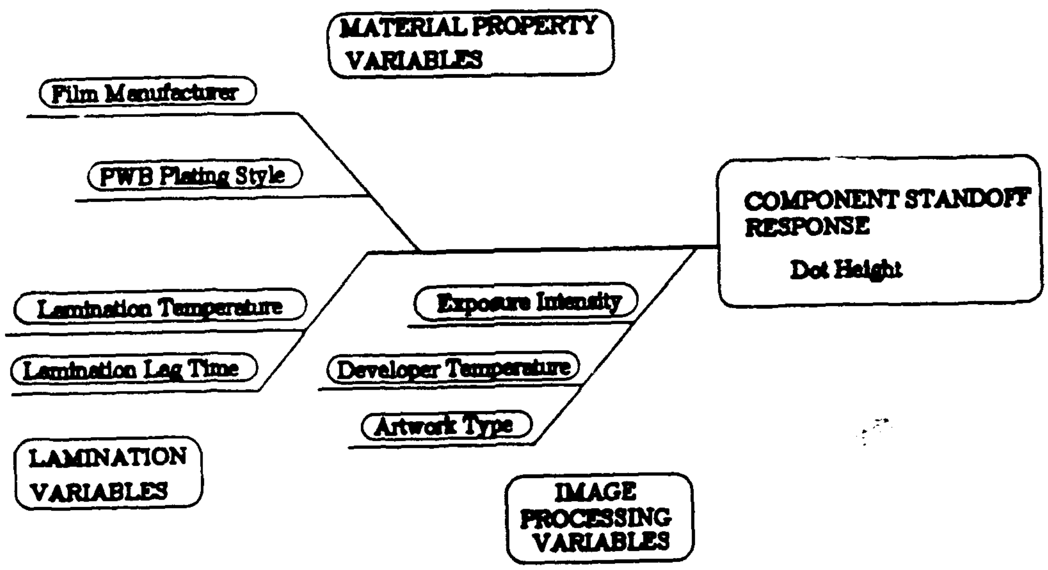

Figure 15. Component Standoff Subtask Cause and Effect Diagram

This subtask involved two eight-run experiments in seven process variables. One of the experiments was a normal fractional factorial design. The second experiment was a reflection of the normal run, and it was run to determine whether interactions existed among the process variables. During the actual performance of the experiment, it was discovered that the thickness of the Dynachem material was 0.5-mil thicker (4.5 mil) than the DuPont material (4.0 mil). A decision was made to procede with the runs without introducing a replicate to the normal run. This decision was made because there was no other dry film solder masks available that were either 4.0 or 4.5 mil in thickness, so no statistical comparison could have been made between competitors materials. At least under the constraints imposed by this current design. Another basis for the decision was that if the columns in the matrix normally set aside for interaction effects indicated neither interaction nor direct process variable effects, then these columns could be regarded as noise. If this turned out to be the situation, then a measure of variability for both the Dynachem and the DuPont products could be calculated; and a determination of process capability for both materials could be established. As a matter of fact this turned out to be the case.

2.3.1.1 Standoff Post Height

2.3.1.1.1 Effects

2.3.1.1.1.1 Analysis. The effects on the FPD response variable, Dry Film Solder Mask Standoff Height, are presented in Table 31. As mentioned in paragraph 2.3, no additional replicates were run that would enable a normal plot of effects and a calculation of process variability. Paragraphs 2.3.2, 2.3.3, and 2.3.4 present an approach that got around this problem. Table 32 is a response table that presents the effects from a folded design. It is a tool that is used to determine whether or not effects associated with process variables that have been assigned to interaction columns in a *fractional factorial matrix design* are real or due to interactions.

Table 31. Effects Table, Normal Design, Single Replicate
Dry Film Solder Mask Standoff Height

Random Order Trial No.:	Resp Obs Values	A Dry Film Vendors DuP	Dyn	B Exposure Int watts 2500	5000	C Developer Temp., F 90	105	AB Dry Film Lam Temp., C -5	+5	AC Dry Film Proc Lag Time, hrs 0.5	24	BC PWB Style fused	air	ABC Process Film Style diazo	halide
4	6.17	6.17		6.17		6.17			6.17		6.17		6.17	6.17	
5	6.15	6.15		6.15			6.15		6.15	6.15		6.15			6.15
8	6.11	6.11			6.11	6.11		6.11			6.11	6.11			6.11
3	5.93	5.93			5.93		5.93	5.93		5.93			5.93	5.93	
1	6.61		6.61	6.61		6.61		6.61		6.61			6.61		6.61
6	6.75		6.75	6.75			6.75	6.75			6.75	6.75		6.75	
7	6.64		6.64		6.64	6.64			6.64	6.64		6.64		6.64	
2	6.80		6.80		6.80		6.80		6.80		6.80		6.80		6.80
Total	51.16	24.36	26.80	25.68	25.48	25.53	25.63	25.40	25.76	25.33	25.83	25.65	25.51	25.49	25.67
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	6.40	6.09	6.70	6.42	6.37	6.38	6.41	6.35	6.44	6.33	6.46	6.41	6.38	6.37	6.42
Effect		0.61		-0.05		0.02		0.09		0.13		-0.04		0.04	

Table 32. Effects Table, Folded Design Dry Film Solder Mask Standoff Height

Random Order Trial No.:	Resp Obs Values	A Dry Film Vendors DuP	Dyn	B Exposure Int watts 2500	5000	C Developer Temp., F 90	105	AB Dry Film Lam Temp., C -5	+5	AC Dry Film Proc Lag Time, hrs 0.5	24	BC PWB Style fused	air	ABC Proces Film Style diazo	halide
6	6.70		6.70		6.70		6.70	6.70		6.70		6.70			6.70
4	6.86		6.86		6.86	6.86		6.86			6.86		6.86	6.86	
8	6.84		6.84	6.84			6.94		6.84	6.84			6.84	6.84	
2	6.84		6.84	6.84		6.84			6.84		6.84	6.84			6.84
1	6.08	6.08			6.08		6.08		6.08		6.08	6.08		6.08	
5	6.14	6.14			6.14	6.14			6.14	6.14			6.14		6.14
7	6.13	6.13		6.13			6.13	6.13			6.13		6.13		6.13
3	6.18	6.18		6.18		6.18		6.18		6.18		6.18		6.18	
Total	51.77	24.53	27.24	25.99	25.78	26.02	25.75	25.87	25.90	25.86	25.91	25.80	25.97	25.96	25.81
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	6.47	6.13	6.81	6.50	6.45	6.51	6.44	6.47	6.48	6.47	6.48	6.45	6.49	6.49	6.45
Effect		0.68		-0.05		-0.07		0.01		0.01		0.04		-0.04	

Table 33, the interaction worksheet combines, subtracts, and compares the results of process variable effects found in the normal and folded experimental runs of fractional factorial designs. Significant, combined normal and folded process variable effects associated with the AB, AC, BC, and ABC locations that are insignificant when the folded design effect is subtracted from the normal design effect, may be assumed to be a real effect and not an interaction. If this is not the case, then the effect certainly includes an interaction between the appropriate A, B, and C process variables; or, if the effects are negligible, there is neither an interaction nor a direct effect.

Table 33. Interaction Effects Dry Film Solder Mask Standoff Height

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	51.16	51.77	51.47	-0.31
A	0.61	0.68	0.65	-0.04
B	-0.05	-0.05	-0.05	0.00
C	0.02	-0.07	-0.03	0.05
AB	0.09	0.01	0.05	0.04
AC	0.13	0.01	0.07	0.06
BC	-0.04	0.04	0.00	-0.04
ABC	0.04	-0.04	0.00	0.04

2.3.1.2 ANOVA

2.3.1.3 Capability Indices

Table 34 presents the analysis of process variability for this experiment. This analysis was made possible by the fact that negligible interaction and the direct process variable effects were measured for the process variables examined with the exception of the Solder Mask Vendor variable. The solder mask vendor process variable was assigned to column A of the experimental matrix. Tables 31, 32, and 33 reveal these facts and support these approaches to the analysis of process variability.

Table 34. Analysis of Process Variability Table
Dry Film Solder Mask Standoff Height

DUPONT VACREL STATISTICS:		DYNACHEM DYNACHEM STATISTICS:	
DATA POINTS:	446	DATA POINTS:	446
AVERAGE:	6.[illegible]	AVERAGE:	6.75
MIN:	5.60	MIN:	6.30
MAX:	[illegible]	MAX:	7.30
STD DEV:	0.18	STD DEV:	0.19
6 SIGMA:	1.10	6 SIGMA:	1.16

Table 35 presents the Cpk/yield data for this dry film solder mask standoff height response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these tables.

Table 35. Cpk Table Dry Film Solder Mask Standoff Height

MATERIAL	RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA TERM
	HEIGHT	4.000	6.000	6.110	1.100
DUPONT	4 TO 6	4.000	6.000	6.75	1.16
DYNACHEM	MILS				
	2*(X(BAR)-LSL)		CP	CPK	PROCESS SIGMA
DUPONT	4.2200		1.8182	-0.2000	-0.600
DYNACHEM	5.5000		1.7241	-1.2931	-3.879
	2*(USL-X(BAR))		YIELD:		
DUPONT	-0.2200		0%, ESSENTIALLY		
DYNACHEM	-1.5000		0%, ESSENTIALLY		

2.3.1.4 Discussion of Standoff Post Height

As evidenced from the analyses of the data collected from these experiments and presented in Tables 31, 32, and 33, the solder mask vendor is the only process variable identified that had any significant affect on the standoff height response variable. This should not be surprising, because the DuPont material used in this experiment was 0.5 mil thinner than the Dynachem product. This difference in thickness just happens to be what these two vendors offer; it is not representative of normal product variability. In addition, it was fortunate to find that not only were other direct effects negligible, but no significant interaction effects were found. The significance of this is that the process variability for both vendors' material could be, and were, evaluated.

The Cp of 1.8 for the DuPont material and 1.7 for the Dynachem material both clearly indicate values that are acceptable for any manufacturing process (this is not to be construed, however, that they should not be constantly improved upon). Note that Table 35 does not report acceptable values for the Cpk indices. This is due to the fact that the process is not centered about the specified range of 4 to 6 mil for the response variable. At the time this experiment was run it was not known what the specification range for the response variable should be, because it is heavily dependent on the cleaning process. Another factor that influences the component standoff height requirement is the reliability of the formed solder joint. Generally, the greater the solder joint height the greater its reliability and the easier it should be to clean underneath the component. As a result of these evaluations and engineering judgment, it is reasonable to change the response variable specification range from 4 to 6 mil to 5 to 7 mil. If this is done, the Cpk value for the DuPont material becomes 1.62, and the corresponding yield becomes, essentially, 100 percent. Since the Dynachem material is 0.5 mil thicker than the DuPont, the response specification range should be changed from 4 to 6 mil to 5.5 to 6.5 mil. When this is done, the Cpk value for the Dynachem material becomes 1.29, and the corresponding yield becomes 99.9 percent.

Based on the previous discussion, it is found that both the DuPont and the Dynachem dry film solder mask materials provide a robust process for component standoffs.

2.3.1.5 Final Run Process Variables

The final experimental run will use the processes utilized during this intermediate phase of the EMPI for PWAs program. The material vendor will not be varied. A single vendor will be selected. This selection will not be based on any conclusion that one of the vendor's product is in any way superior to the other's product. The selection for this program will be based on which product can provide the optimum thickness required for TRW MEAD's unique design and application.

2.3.2 Subtask 3, Experiment 2, Printed Wiring Assembly Cleaning

The details of the printed wiring assembly cleaning experiment are presented in Appendix D of this report. The thrust of the experiment is presented in Figure 16. The data collection and analysis for the visual and ionic cleanliness response variables have been completed and are presented in this report.

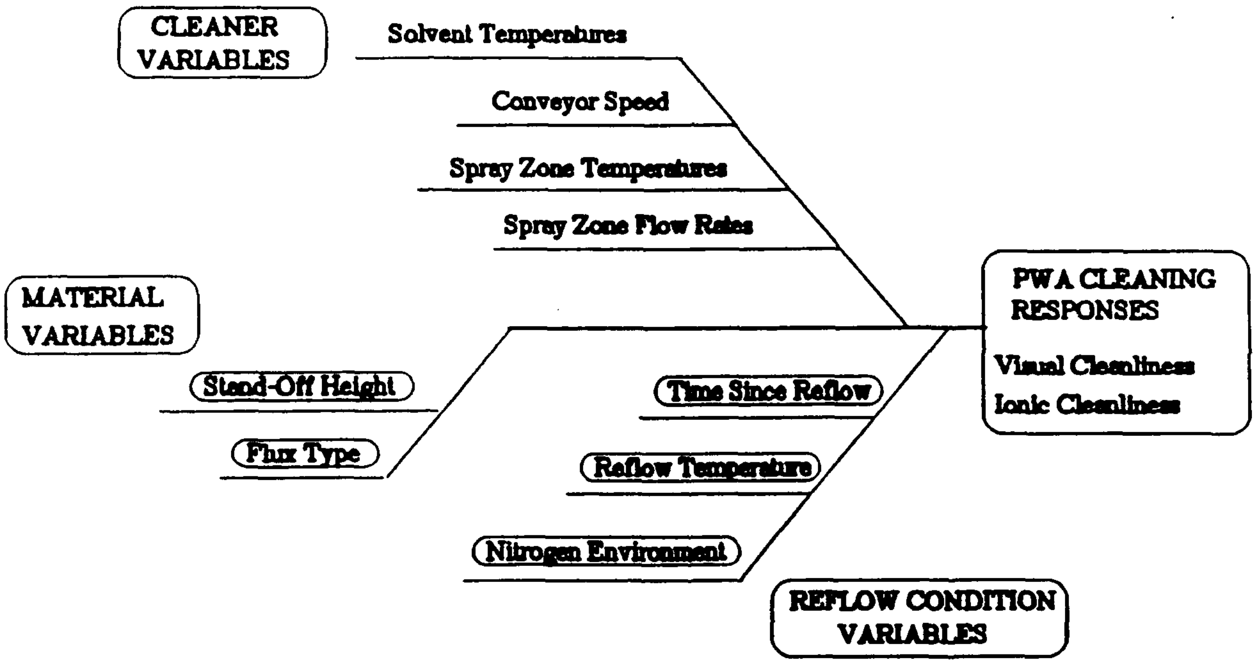

Figure 16. PWA Cleaning Subtask Cause and Effect Diagram

This subtask involved three 8-run experiments in five process variables. After filling columns A, B, and C with process variables, the fourth process variable was placed in column ABC and the fifth in column AB. Two of the experiments were replications run to determine the variability of the process. The third experiment was a reflection of the replicates, and it was run to determine whether interactions existed among the process variables.

2.3.3 Visual Cleanliness of the PWA

2.3.3.1 Effects

2.3.3.1.1 Analysis. The effects on the cleanliness response variable, Visual Cleanliness, are presented in Tables 36 and 37. Figure 17 is a normal plot of the ranked effects taken from Table 36. Table 38 is an interaction table; it is a tool that is used to determine whether or not effects associated with process variables that have been assigned to interaction columns in a fractional factorial matrix design are real or due to interactions. In this particular experiment, columns AB and ABC are tested for possible conflicts.

A general explanation of response tables, normal plots, and interaction effects tables is presented in paragraph 2.1.1.1.1.

2.3.3.2 ANOVA

2.3.3.3 Capability Indices

Tables 39 and 40 present the ANOVA and Cpk/yield data, respectively, for the Visual Cleanliness response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.3.3.4 Discussion of Visual Cleanliness

An examination of the visual cleanliness "effects" data in Table 36 indicates that the nitrogen supply process variable and the following two interaction columns AC and BC have the most significant "effect" values. It is not clear why the interaction columns would have such a significant value (-.75 and .75, respectively) when their related first order columns A, B, and C have a relatively less significant value (-.25, .25, and .25, respectively).

The normal plot for this replicated experiment does not reveal that any of the process variables are exerting any significant affects on the response variable.

The data presented in the interaction table is not straightforward. Note that the effects of the folded experiment, Y for E(2), is nearly four times greater than the value for E(1). One would expect these Y values to be nearly equivalent.

The problem with evaluating the visual cleanliness response variable is in the precision with which the visual cleanliness is measured. In this experiment, an inspector was given a visual standard against which to compare the assembled and cleaned PWAs. The visual standards were ranked from 1 to 4 with 1 being the best condition and 4 being the worst. It was assumed that the gradation between the standards ranked 1 and 2 were the same as between 2 and 3, etc. There was no way to justify this assumption. In addition, it is known that visual comparisons can be uncertain. A decision was made to procede with a visual inspection criteria, because military specifications governing the assembly of PWBs all impose a visual inspection criteria.

Table 36. Effects Table, Normal Design Visual Cleanliness

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Reflow Temp. deg C 205	220	B Time Since Reflow, mins 0	30	C Standoff Height, mils 4	6	AB Nitrogen Supply off	on	AC *******ERROR TERMS*********		BC		ABC Solder Paste Vendor Metech	Multic
1	0.000	0.000	0.000	0.000		0.000		0.000			0.000		0.000		0.000	0.000	
2	0.000	0.000	0.000	0.000		0.000			0.000		0.000	0.000		0.000			0.000
3	0.000	0.000	0.000	0.000			0.000	0.000		0.000			0.000	0.000			0.000
4	4.000	0.000	2.000	2.000			2.000		2.000	2.000		2.000			2.000	2.000	
5	0.000	2.000	1.000		1.000	1.000		1.000		1.000		1.000			1.000		1.000
6	0.000	0.000	0.000		0.000	0.000			0.000	0.000			0.000	0.000		0.000	
7	0.000	0.000	0.000		0.000		0.000	0.000			0.000	0.000		0.000		0.000	
8	0.000	0.000	0.000		0.000		0.000		0.000		0.000		0.000		0.000		0.000
Total			3.00	2.00	1.00	1.00	2.00	1.00	2.00	3.00	0.00	3.00	0.00	0.00	3.00	2.00	1.00
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			0.375	0.500	0.250	0.250	0.500	0.250	0.500	0.750	0.000	0.750	0.000	0.000	0.750	0.500	0.250
Averages Effect (1<2>-1<1>)				-0.250		0.250		0.250		-0.750		-0.750		0.750		-0.250	

Table 37. Effects Table, Folded Design Visual Cleanliness

Std Order Trial No.	Resp Obs Values	A Reflow Temp, deg C 205	220	B Time Since Reflow, mins 0	30	C Standoff Height, mils 4	6	AB Nitrogen Supply off	on	AC *******ERROR		BC TERMS*********		ABC Solder Vendor Metech	Paste Multic
1	1.00		1.00		1.00		1.00	1.00		1.00		1.00			1.00
2	4.00		4.00		4.00	4.00		4.00			4.00		4.00	4.00	
3	0.00		0.00	0.00			0.00		0.00	0.00			0.00	0.00	
4	1.00		1.00	1.00		1.00			1.00		1.00	1.00			1.00
5	0.00	0.00			0.00		0.00		0.00		0.00	0.00		0.00	
6	5.00	5.00			5.00	5.00			5.00	5.00			5.00		5.00
7	1.00	1.00		1.00			1.00	1.00			1.00		1.00		1.00
8	1.00	1.00		1.00		1.00		1.00		1.00		1.00		1.00	
Total	13.00	7.00	6.00	3.00	10.00	11.00	2.00	7.00	6.00	7.00	6.00	3.00	10.00	5.00	8.00
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	1.63	1.75	1.50	0.75	2.50	2.75	0.50	1.75	1.50	1.75	1.50	0.75	2.50	1.25	2.00
Effect		-0.25		1.75		-2.25		-0.25		-0.25		1.75		0.75	

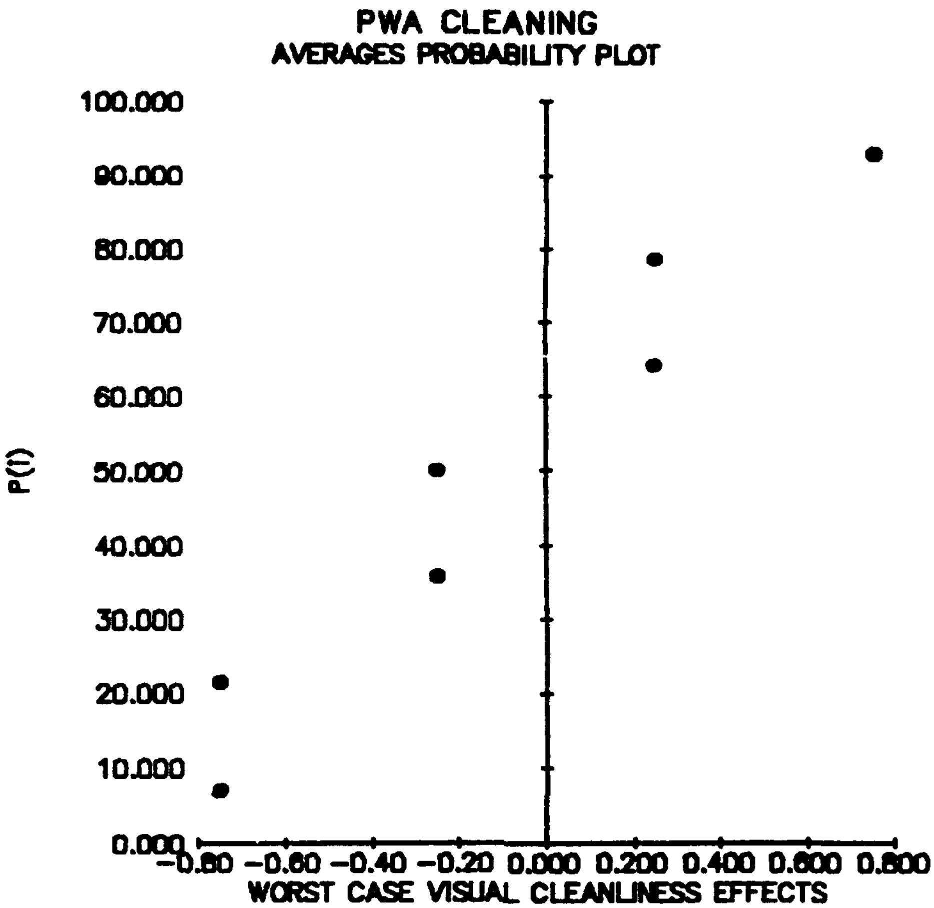

Figure 17. Normal Plot Visual Cleanliness

Table 38. Interaction Effects Visual Cleanliness

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	0.38	1.63	1.00	-0.63
A	-0.25	-0.25	-0.25	0.00
B	0.25	1.75	1.00	-0.75
C	0.25	-2.25	-1.00	1.25
AB	-0.75	-0.25	-0.50	-0.25
AC	-0.75	-0.25	-0.50	-0.25
BC	0.75	1.75	1.25	-0.50
ABC	-0.25	0.75	0.25	-0.50

Table 39. ANOVA Table Visual Cleanliness

RESPONSE VARIABLE: VISUAL CLEANLINESS, WORST CASE

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	REF TEMP	0.125	1	0.125	NA	NA	0.0%
2		P	LAG TIME	0.125	1	0.125	NA	NA	0.0%
3		P	STANDOFF	0.125	1	0.125	NA	NA	0.0%
4			N2	1.125	1	1.125	9	0.04	25.8%
5			ERROR	1.125	1	1.125	9	0.04	25.8%
6			ERROR	1.125	1	1.125	9	0.04	25.8%
7		P	PASTE	0.125	1	0.125	NA	NA	0.0%
POOLED ERROR:				0.5	4	0.125			22.6%
TOTAL(CORRECTED):				3.875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 0.38 6 SIGMA ----> 2.74

Table 40. Cpk Table Visual Cleanliness

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PWA CLEANLINESS WORST CASE 0-1	0.00	1.00	0.38	2.55

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
0.76	0.39	0.49	1.46

2*(USL-X(BAR))		
1.24	YIELD:	85.51%

This criteria is often expressed in such a manner that "no" visual contamination is permitted. This results in many discussions on the factory floor and in material review board (MRB) meetings regarding the disposition of assemblies that have been found to have "visual" contamination. In addition to a cleanliness defect being an obvious contamination, PWAs often have cleanliness defects that are stains and blemishes. These cannot always be accurately determined to be unacceptable visual contamination. When this happens there is always a chance that a requirement to rework is imposed only to be "on the safe side," and, of course, a real defect may be dispositioned "use as is" when in fact it should be reworked if they are contaminated at all.

The point being illustrated here is that the visual contamination criteria does not lend itself to a measurement technique that is precise enough to yield meaningful statistics.

The data in the ANOVA table for the visual cleanliness response variable, Table 39, is in agreement with the effects table and the normal plot of the associated effects. This table indicates that the nitrogen process variable and two interaction columns have statistically significant influences on the response variable. As shown previously, the response table indicated that the nitrogen response variable was a significant contributor.

The Cpk/yield table, Table 40, demonstrates that this process needs improvement as far as visual contamination requirements are concerned. A process yield of 85 percent is not acceptable.

2.3.4 Ionic Cleanliness of the PWA

2.3.4.1 Effects

2.3.4.1.1 Analysis. The effects on the response variable, Ionic Contamination, are presented in Tables 41 and 42. Figure 18 is a normal plot of the ranked effects taken from Table 42. Table 43 is an interaction table; it is a tool that is used to determine whether or not effects associated with process variables that have been assigned to interaction columns in a fractional factorial matrix design are real or due to interactions. In this particular experiment, columns AB and ABC are tested for possible conflicts.

A general explanation of response tables, normal plots, and interaction effects tables is presented in paragraph 2.1.1.1.1.

Table 41. Effects Table, Normal Design Ionic Contamination

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Reflow Temp, deg C 205	220	B Time Since Reflow, mins 0	30	C Standoff Height, mils 4	6	AB Nitrogen Supply off	on	AC ******ERROR		BC TERMS*********		ABC Solder Paste Vendor Metech	Multic
1	2.850	4.540	3.695	3.695		3.695		3.695			3.695		3.695		3.695	3.695	
2	3.050	2.530	2.790	2.790		2.790			2.790		2.790	2.790		2.790			2.790
3	3.290	3.070	3.180	3.180			3.180	3.180		3.180			3.180	3.180			3.180
4	3.540	4.780	4.160	4.160			4.160		4.160	4.160		4.160			4.160	4.160	
5	3.730	2.530	3.130		3.130	3.130		3.130		3.130		3.130			3.130		3.130
6	2.480	2.960	2.720		2.720	2.720			2.720	2.720			2.720	2.720		2.720	
7	6.420	2.850	4.635		4.635		4.635	4.635			4.635	4.635		4.635		4.635	
8	2.340	2.770	2.555		2.555		2.555		2.555		2.555		2.555		2.555		2.555
Total			26.86	13.83	13.04	12.34	14.53	14.64	12.23	13.19	13.68	14.72	12.15	13.33	13.54	15.21	11.66
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			3.358	3.456	3.260	3.084	3.633	3.660	3.056	3.297	3.419	3.679	3.038	3.331	3.385	3.803	2.914
Averages Effect (1<2>-1<1>)				-0.196		0.549		-0.604		0.121		-0.641		0.054		-0.889	

Table 42. Effects Table, Folded Design Ionic Contamination

Std Order Trial No.	Resp Obs Values	A Reflow Temp, deg C 205	220	B Time Since Reflow, mins 0	30	C Standoff Height, mils 4	6	AB Nitrogen Supply off	on	AC *******ERROR		BC TERMS*********		ABC Solder Paste Vendor Metech	Multic
1	2.39		2.39		2.39		2.39	2.39		2.39		2.39			2.39
2	3.86		3.86		3.86	3.86		3.86			3.86		3.86	3.86	
3	3.29		3.29	3.29			3.29		3.29	3.29			3.29	3.29	
4	2.45		2.45	2.45		2.45			2.45		2.45	2.45			2.45
5	3.29	3.29			3.29		3.29		3.29		3.29	3.29		3.29	
6	2.91	2.91			2.91	2.91			2.91	2.91			2.91		2.91
7	3.69	3.69		3.69			3.69	3.69			3.69		3.69		3.69
8	3.93	3.93		3.93		3.93		3.93		3.93		3.93		3.93	
Total	25.81	13.82	11.99	13.36	12.45	13.15	12.66	13.87	11.94	12.52	13.29	12.06	13.75	14.37	11.44
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	3.23	3.46	3.00	3.34	3.11	3.29	3.17	3.47	2.99	3.13	3.32	3.02	3.44	3.59	2.86
Effect		-0.46		-0.23		-0.12		-0.48		0.19		0.42		-0.73	

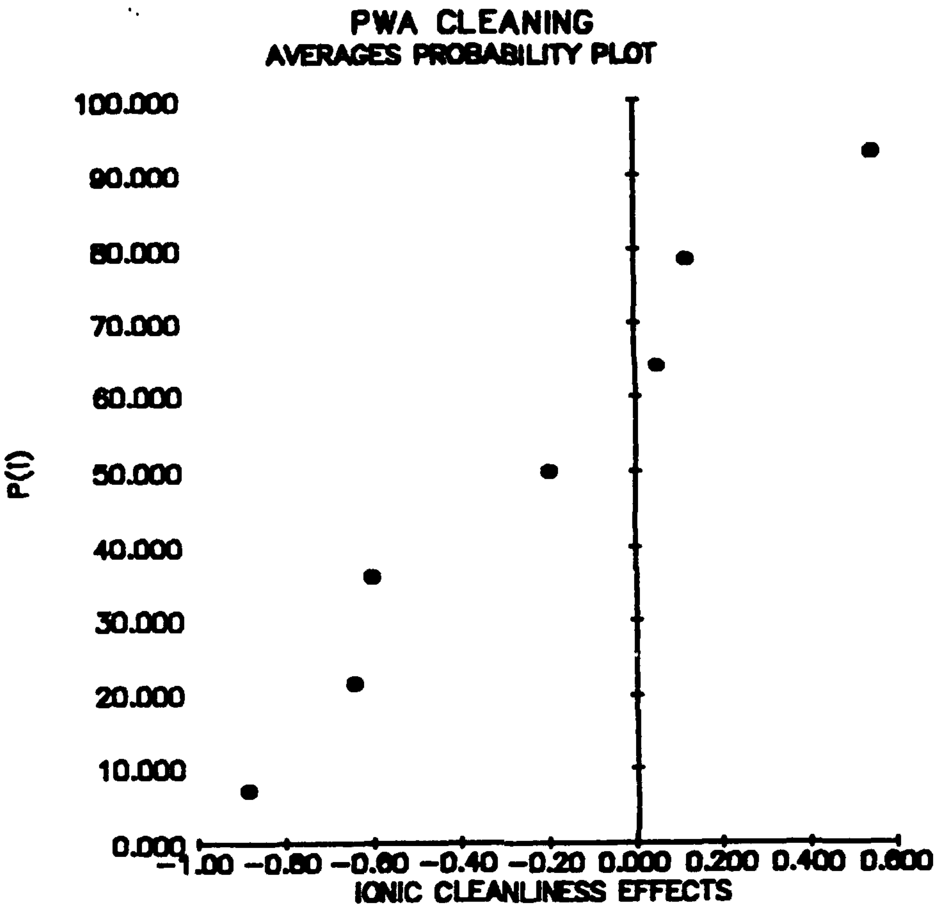

Figure 18. Normal Plot Ionic Contamination

Table 43. Interaction Table Ionic Contamination

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	3.36	3.23	3.29	0.06
A	-0.20	-0.46	-0.33	0.13
B	0.55	-0.23	0.16	0.39
C	-0.60	-0.12	-0.36	-0.24
AB	0.12	-0.48	-0.18	0.30
AC	-0.64	0.19	-0.23	-0.42
BC	0.05	0.42	0.24	-0.18
ABC	-0.89	-0.73	-0.81	-0.08

2.3.4.2 ANOVA

2.3.4.3 Capability Indices

Tables 44 and 45 present the ANOVA and Cpk/yield data, respectively, for the Ionic Contamination response variable. Paragraph 1.1.3 explains the methodology behind the derivation of these types of tables.

Table 44. ANOVA Table Ionic Contamination

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	REF TEMP	0.077028	1	0.077028	NA	NA	0.0%
2		P	LAG TIME	0.602253	1	0.602253	NA	NA	0.0%
3			STANDOFF	0.729028	1	0.729028	4.081	0.11	14.3%
4		P	N2	0.029403	1	0.029403	NA	NA	0.0%
5			ERROR	0.822403	1	0.822403	4.604	0.10	16.7%
6		P	ERROR	0.005778	1	0.005778	NA	NA	0.0%
7			PASTE	1.579753	1	1.579753	8.844	0.04	36.4%
POOLED ERROR:				0.714462	4	0.178615			32.5%
TOTAL(CORRECTED):				3.845646	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 3.36 6 SIGMA ----> 3.00

Table 45. Cpk Table Ionic Contamination

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PWA CLEANLINESS IONIC 0-10	0.00	10.00	3.36	3.00

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
6.72	3.33	4.43	13.28
2*(USL-X(BAR))			
13.28	YIELD:	100%, ESSENTIALLY	

2.3.4.4 Discussion of Ionic Cleanliness

An examination of the ionic contamination "effects" data (equivalent micrograms of NaCl) in Table 41 indicate that the Solder Paste Vendor, AC interaction, Standoff Height, and Time Since Reflow process variables have affects on the response variable. This conclusion is not supported by the normal plot, Figure 18, which suggests that all of the effects can be explained by normal variation in the experimental data. The effects indicate that by reducing the lag time between reflow and cleaning, using Multicore rather than Metech solder paste, and using a standoff height of 6 mil will reduce the ionic contamination compared to the alternate levels for these process variables. The interaction table, Table 43, does not provide any significant indication of interaction effects.

The ANOVA table, Table 44, supports the effects table in indicating that the solder paste process variable has the most significant affect on the process variable. This information will be useful in the decision process used to select the solder paste. Also to be considered are the results from the infrared reflow experiment and the solder paste placement experiment. The solder paste process variable is also indicated as a significant variable affecting the response variable.

The Cpk table, Table 45, demonstrates that as far as the ionic contamination response variable is concerned, the process is robust with a yield of 100 percent.

2.3.5 Final Run Process Variables

Component standoff height is going to be varied between 4 and 6 mil even though this experiment indicates that the greater the better for this process variable. The reason that it will be varied is that this process variable was not checked against both styles of PWB finishes, fused and solder dipped and hot air leveled. It is recognized that the 6-mil standoff is preferable as far as ionic contamination is concerned.

The solder paste vendor is also going to be varied, because it was never tested against the different styles of PWB finishes either.

The lag time between reflow and cleaning will be reduced from 0 to 30 min to 0 to 5 min. This process range is very easy to implement, and there is no reason not to.

The nitrogen supply will be toggled on and the reflow temperature profile will be set to the 220°C level.

2.4 SUBTASK 4, FINE PITCH DEVICE LEAD FORMING

The details of the fine pitch device (FPD) lead forming experiment are presented in Appendix C of this report. The thrust of the experiment is presented in Figure 19. All of the response data for all of the responses have been collected and reduced and are presented in this report. The FPD lead coplanarity test was not successfully completed. This is explained in this report. A single point experiment was run subsequently with workable data collected. This rerun is not presented in this report.

This subtask involved two 8-run experiments in three process variables. The second experiment was a replicate of the first and was used to determine the variability of the process in addition to the process mean. Since this was a full, factorial design, no reflected runs were required to identify possible interactions between process variables that might have masked assigned process variable effects.

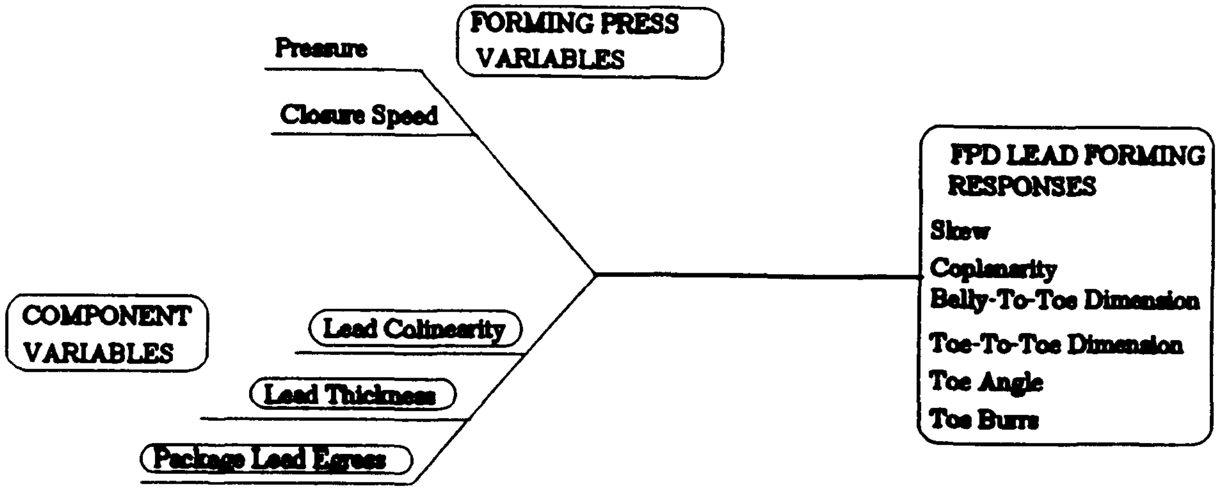

Figure 19. FPD Lead Forming Subtask Cause and Effect Diagram

2.4.1 Fine Pitch Device Lead Skew

2.4.1.1 Effects

2.4.1.1.1 Analysis. The effects of the three process variables on the response variable, FPD Lead Skew, are presented in Table 46. Figure 20 is a normal plot of the ranked effects taken from Table 46. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.4.1.2 ANOVA

2.4.1.3 Capability Indices

Tables 47 and 48 present the ANOVA and Cpk/yield data, respectively, for the FPD Lead Skew response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.4.1.4 Discussion of Lead Skew

An examination of the FPD lead skew "effects" data in Table 46 indicates that initial FPD lead skew has a very strong effect on the final lead skew of the FPD package. Lead thickness and package style have a somewhat smaller effect on this response. This lead skew associated with the process variable was induced prior to forming and trimming the part. The response variable, lead skew, is a measure of how much above and beyond the induced lead skew occurred.

The pattern of the normal plot in Figure 47 supports the effects data. The upper right data point, associated with the initial lead skew variable, falls significantly to the right of an imaginary straight line drawn through the remaining points. This is the condition that allows one to conclude that the effect represented by that point is not one that might be expected if the effect were due only to normal variation. Although the other points on this figure do not exactly fit a straight line, their deviation is not significant.

Table 46. Effects Table, Normal Design FPD Lead Skew

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Package Style Diacon	Kyocera	B Lead Thickness, mils 5	8	C Lead Skew, mils -3	3	AB **************	INTERACTION	AC AND	ERROR	BC TERMS	*******	ABC *******	
1	-1.960	-1.280	-1.620	-1.620		-1.620		-1.620			-1.620		-1.620		-1.620	-1.620	
2	1.430	2.180	1.805	1.805		1.805			1.805		1.805	1.805		1.805			1.805
3	-1.520	-1.520	-1.520	-1.520			-1.520	-1.520		-1.520			-1.520	-1.520			-1.520
4	2.780	2.160	2.470	2.470			2.470		2.470	2.470		2.470			2.470	2.470	
5	-1.390	-2.030	-1.710		-1.710	-1.710		-1.710		-1.710		-1.710			-1.710		-1.710
6	1.980	2.280	2.130		2.130	2.130			2.130	2.130			2.130	2.130		2.130	
7	-0.930	-0.780	-0.855		-0.855		-0.855	-0.855			-0.855	-0.855		-0.855		-0.855	
8	3.070	2.440	2.755		2.755		2.755		2.755		2.755		2.755		2.755		2.755
Total			3.46	1.14	2.32	0.61	2.85	-5.71	9.16	1.37	2.09	1.71	1.74	1.56	1.89	2.13	1.33
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			0.432	0.284	0.580	0.151	0.713	-1.426	2.290	0.343	0.521	0.428	0.436	0.390	0.474	0.531	0.333
Averages Effect (1<2>-1<1>)				0.2963		0.5613		3.7163		0.1788		0.0087		0.0837		-0.1988	

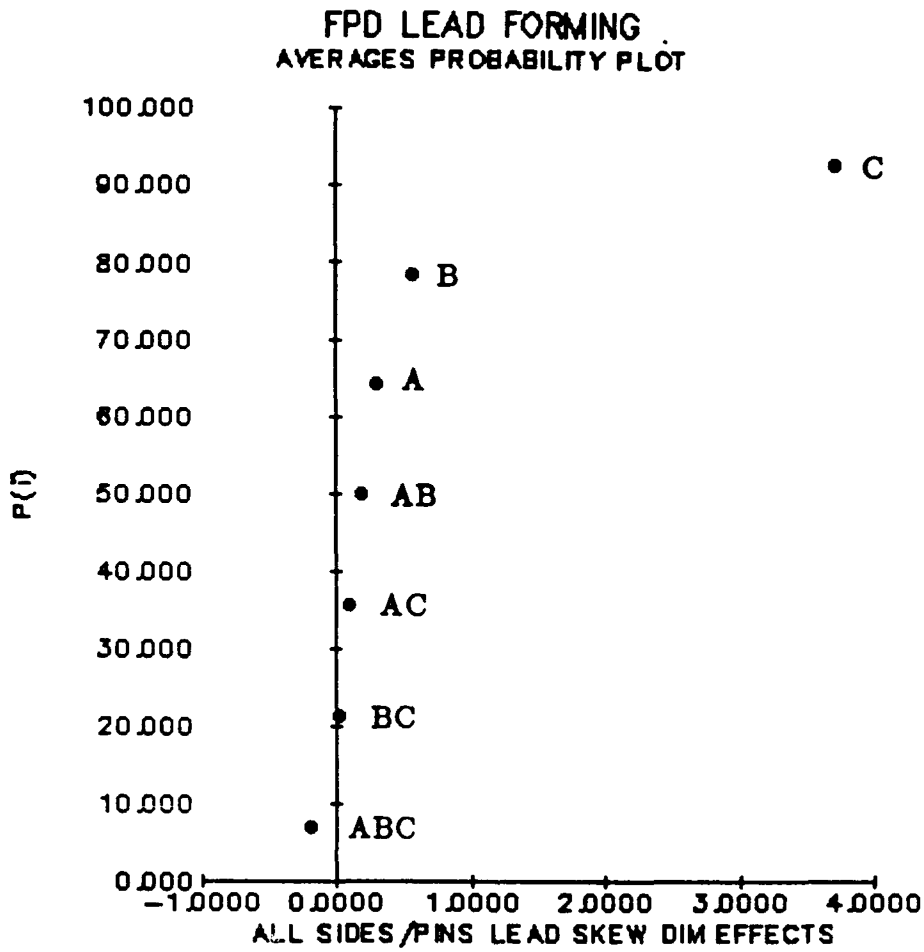

Figure 20. Normal Plot FPD Lead Skew

Table 47. ANOVA Table FPD Lead Skew

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PKG STYLE	0.175528	1	0.175528	4.469	0.10	0.5%
2			LEAD THK	0.630003	1	0.630003	16.04	0.02	2.1%
3			LEAD SKEW	27.62102	1	27.62102	703.3	0.00	96.5%
4		P	ERROR	0.063903	1	0.063903	NA	NA	0.0%
5		P	ERROR	0.000153	1	0.000153	NA	NA	0.0%
6		P	ERROR	0.014028	1	0.014028	NA	NA	0.0%
7		P	ERROR	0.079003	1	0.079003	NA	NA	0.0%
POOLED ERROR:				0.157087	4	0.039271			1.0%
TOTAL(CORRECTED):				28.58364	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 0.43 6 SIGMA ----> 5.45

Table 48. Cpk Table FPD Lead Skew

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD LEAD SKEW OVERALL -2 TO 2. MILS	-2.00	2.00	0.43	5.45

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
4.86	0.73	0.58	1.73
2*(USL-X(BAR))			
3.14	YIELD:	91.60%	

The data in the ANOVA table for the FPD lead skew, Table 47, is in agreement with the data in the effects table. Although it is statistically much less significant than lead skew, the lead thickness process variable is indicated as of some importance.

The Cpk/yield table, Table 48, demonstrates that this process is in need of improvement. Improvement can best be achieved by reducing the "6 sigma" variable, and this can be attacked by reducing the initial FPD lead skew. In fact, the forced range of the lead skew process variable is much greater than normal. This process variable can be expected to lie well within a range of -1 to 1 mil, and subsequent additional skew and associated variability will be reduced significantly. The mean value for the skew is pretty well centered.

2.4.2 Fine Pitch Device Lead Coplanarity

2.4.2.1 Effects

2.4.2.1.1 Analysis. The effects of the three process variables on the response variable, FPD Lead Skew, are presented in Table 49. Figure 21 is a normal plot of the ranked effects taken from Table 49. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.4.2.2 ANOVA

2.4.2.3 Capability Indices

Tables 50 and 51 present the ANOVA and Cpk/yield data, respectively, for the FPD Lead Coplanarity variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.4.2.4 Discussion of Lead Coplanarity

An examination of the FPD lead coplanarity "effects" data in Table 49 indicates that initial FPD lead skew has a very strong effect on the final lead skew of the FPD package. An AC and BC interaction are also indicated as having significant affect on the response variable.

The pattern of the normal plot in Figure 21 does not support the data presented in the effects table. The normal plot indicates that the values for the process variables all lie within values that would be due to normal process variability.

The data in the ANOVA table for the FPD lead coplanarity, Table 50, are in agreement with the data in the effects table. The significance of the effect values are ranked from "Lead Skew" to AC interaction to BC interaction.

The Cpk/yield table, Table 51, demonstrates that this process is in need of improvement. As with the Lead Skew response, improvement can best be achieved by reducing the "6 sigma" variable, and this can be attacked by reducing the initial FPD lead skew. In fact, the forced range of the lead skew process variable is much greater than would be normally encountered. This process variable can be expected to lie well within a range of -1 to 1 mil, and subsequent additional skew and associated variability will be reduced significantly. The mean value for the coplanarity is way out of range, being more than twice the maximum specification limit of 4 mil. Some of this out of range condition has been attributed to dealing with packages with two different lead frame materials. The Diacon package uses alloy 42 in the lead frame while the Kyocera package uses Kovar. These alloys have different spring back properties which affect several of the lead forming responses. In addition, the Diacon package was difficult to remove from the forming die because its ceramic body was slightly larger than the Kyocera's body. The geometry of the Diacon package differed from the Kyocera package at the interface between the lead frame and the package body. The leads from the Diacon package exit from the side of the package much like the leads from a Cerdip. The leads from the Kyocera package exit from the package from the top surface in much the same way as a ceramic DIP.

Table 49. Effects Table, Normal Design FPD Lead Coplanarity

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Package Style Diacon	Kyocera	B Lead Thickness, mil 5	8	C Lead Skew, mils -3	3	AB ***INTERACTION AND ERROR TERMS***		AC		BC		ABC	
1	4.300	5.900	5.100	5.100		5.100		5.100			5.100		5.100		5.100	5.100	
2	18.100	10.000	14.050	14.050		14.050			14.050		14.050	14.050		14.050			14.050
3	6.800	10.100	8.450	8.450			8.450	8.450		8.450			8.450	8.450			8.450
4	7.300	14.100	10.700	10.700			10.700		10.700	10.700		10.700			10.700	10.700	
5	4.100	7.200	5.650		5.650	5.650		5.650		5.650		5.650			5.650		5.650
6	7.700	6.800	7.250		7.250	7.250			7.250	7.250			7.250	7.250		7.250	
7	8.200	11.000	9.600		.600		9.600	9.600			9.600	9.600		9.600		9.600	
8	10.800	8.400	9.600		9.600		9.600		9.600		9.600		9.600		9.600		9.600
Total			70.40	38.30	32.10	32.05	38.35	28.80	41.60	32.05	38.35	40.00	30.40	39.35	31.05	32.65	37.75
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			8.800	9.575	8.025	8.013	9.588	7.200	10.400	8.013	9.588	10.000	7.600	9.838	7.763	8.163	9.438
Averages Effect (1<2>-1<1>)				-1.550		1.575		3.200		1.575		-2.400		-2.075		1.275	

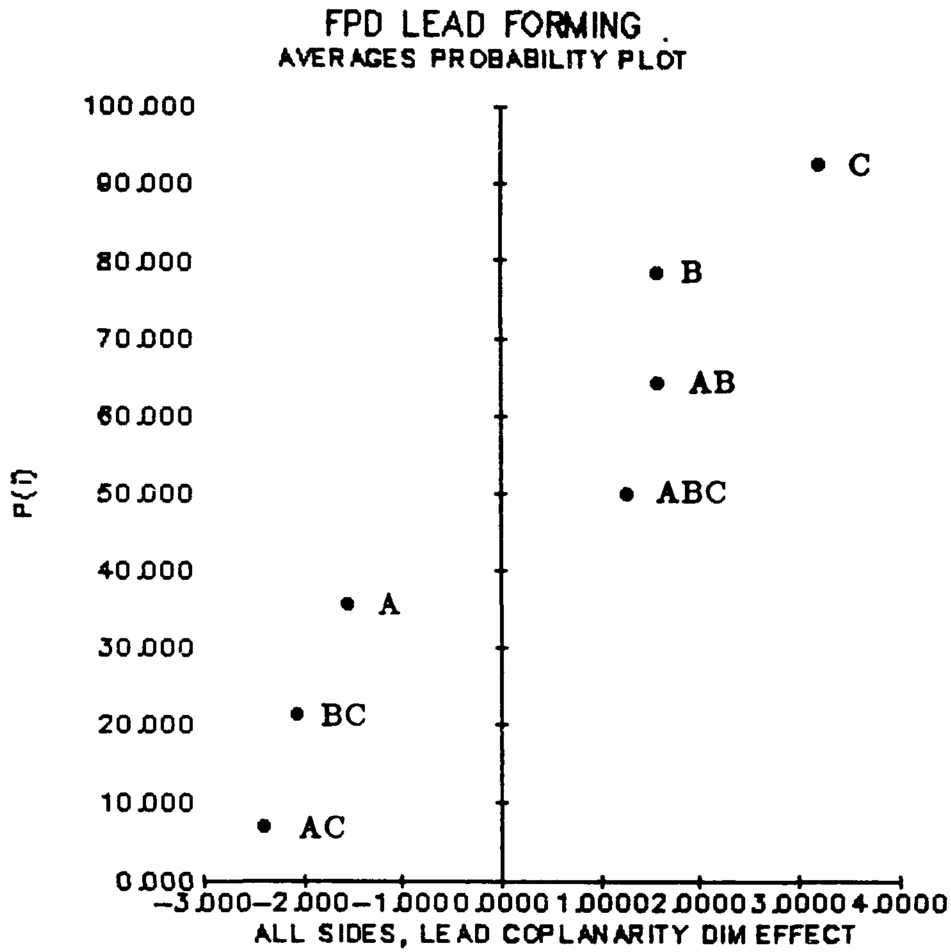

Figure 21. Normal Plot FPD Lead Coplanarity

Table 50. ANOVA Table FPD Lead Coplanarity

```
:----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------:
FACTOR  CD  PL    NAME       SS       DF      MS      F    PROB   %
------- --- -- --------- -------- ---- -------- ----- ---- ------
      1      P  PKG STYLE    4.805    1    4.805    NA    NA    0.0%
      2         LEAD THK   4.96125    1  4.96125 1.231 0.38    1.6%
      3         LEAD SKEW    20.48    1    20.48 5.084 0.15   28.1%
      4         ERROR      4.96125    1  4.96125 1.231 0.38    1.6%
      5         ERROR        11.52    1    11.52 2.859 0.23   12.8%
      6         ERROR      8.61125    1  8.61125 2.137 0.28    7.8%
      7      P  ERROR      3.25125    1  3.25125    NA    NA    0.0%
POOLED ERROR:              8.05625    2 4.028125               48.1%
TOTAL(CORRECTED):            58.59    7

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

        X(BAR):     8.80  6 SIGMA ---->   13.24
```

Table 51. Cpk Table FPD Lead Coplanarity

```
RESP               SPEC LIMIT
VAR                LOWER   UPPER    X(BAR)  6 SIGMA(total) TERM

FPD LEAD COPL      0.00    4.00     8.80         13.24
OVERALL
-0 TO 4. MILS

 2*(X(BAR)-LSL)                            PROCESS
                          CP      CPK      SIGMA
     17.60
                          0.30    -0.73    -2.18
 2*(USL-X(BAR))

     -9.60               YIELD:  0%. ESSENTIALLY
```

The design data for the Diacon package did not indicate that the forming die would be a problem, but it was. The lesson learned from this experiment is that until a flexible, automatable forming die is developed, only single style packages should be utilized in the fixed die of the Gelzer robot.

In accordance with the Taguchi philosophy, the differences between the levels of a process variable should be large so that significant effects will be easier to spot. The down side of this idea though is to get such a wide range that the experiment will not work correctly.

2.4.3 Fine Pitch Device Belly-to-Toe Dimension

2.4.3.1 Effects

2.4.3.1.1 Analysis (Discussion). The belly-to-toe response variable data was not acceptable for analysis. The reasons for this are due to the different lead frame materials as described previously in the discussion of the lead coplanarity response results. This caused such a scattering of data that the only conclusion that could be reached is that these two styles of packages should not be used together with the fixed die now attached to the Gelzer robot. Subsequent experiments will not use the Diacon package. This is no reflection on the value of the Diacon package. The decision to use it in this original experiment is entirely TRW MEAD's. The choice to stay with the Kyocera (or NTK) package is due to the fact that these packages are the overwhelming choice of semi-conductor vendors.

A single point experiment is being run just prior to the final experiment to gather data for Cpk and yield values.

2.4.4 Fine Pitch Device Toe-to-Toe Dimension

2.4.4.1 Effects

2.4.4.1.1 Analysis. The effects of the three process variables on the response variable, FPD Lead Toe-to-Toe Dimension, are presented in Table 52. Figure 22 is a normal plot of the ranked effects taken from Table 52. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.4.4.2 ANOVA

2.4.4.3 Capability Indices

Tables 53 and 54 present the ANOVA and Cpk/yield data, respectively, for the FPD lead coplanarity variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.4.4.4 Discussion of Toe-to-Toe Dimension

An examination of the FPD lead toe-to-toe dimension "effects" data in Table 52 indicates that FPD package style has a strong effect on the final package lead toe-to-toe dimension. No other effects appear to be significant.

The pattern of the normal plot in Figure 22 strongly supports the data presented in the effects table. The lower left position for the point associated with the Package Style process variable which places it to the left of the lower end of an imaginary straight line drawn through the remaining points is one of the indicators for non-normal significance. Other points vary from a straight line, but they do not vary enough to be considered significant.

The data in the ANOVA table for the FPD lead coplanarity, Table 53, provide a stronger indication that the FPD package styles effects are statistically significant. Lead thickness is a much less significant contributor to variability.

The Cpk/yield table, Table 54, demonstrates that this process is in need of improvement. As with the Lead Skew response, improvement can best be achieved by reducing the "6 sigma" variable, and this can be attacked by eliminating the use of two different package styles in the lead forming die on the Gelzer robot.

Table 52. Effects Table, Normal Design FPD Lead Toe-to-Toe Dimension

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Package		Lead		Lead									
Trial	Variables			Style		Thickness, mils		Skew, mils		**************	INTERACTION AND ERROR TERMS					*******	*******
No.	Normal	Replic	Avg.	Diacon	Kyocera	5	8	-3	3								
1	1.228	1.229	1.228	1.228		1.228		1.228			1.228		1.228		1.228	1.228	
2	1.227	1.230	1.229	1.229		1.229			1.229		1.229	1.229		1.229			1.229
3	1.227	1.226	1.226	1.226			1.226	1.226		1.226			1.226	1.226			1.226
4	1.223	1.230	1.226	1.226			1.226		1.226	1.226		1.226			1.226	1.226	
5	1.213	1.215	1.214		1.214	1.214		1.214		1.214		1.214			1.214		1.214
6	1.216	1.217	1.216		1.216	1.216			1.216	1.216			1.216	1.216		1.216	
7	1.215	1.213	1.214		1.214		1.214	1.214			1.214	1.214		1.214		1.214	
8	1.214	1.215	1.214		1.214		1.214		1.214		1.214		1.214		1.214		1.214
Total			9.77	4.91	4.86	4.89	4.88	4.88	4.89	4.88	4.89	4.88	4.89	4.89	4.88	4.89	4.88
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.221	1.227	1.215	1.222	1.220	1.221	1.221	1.221	1.221	1.221	1.221	1.221	1.221	1.221	1.221
Averages Effect (1<2>-1<1>)				-0.0128		-0.0017		0.0007		0.0005		0.0006		-0.0006		-0.0006	

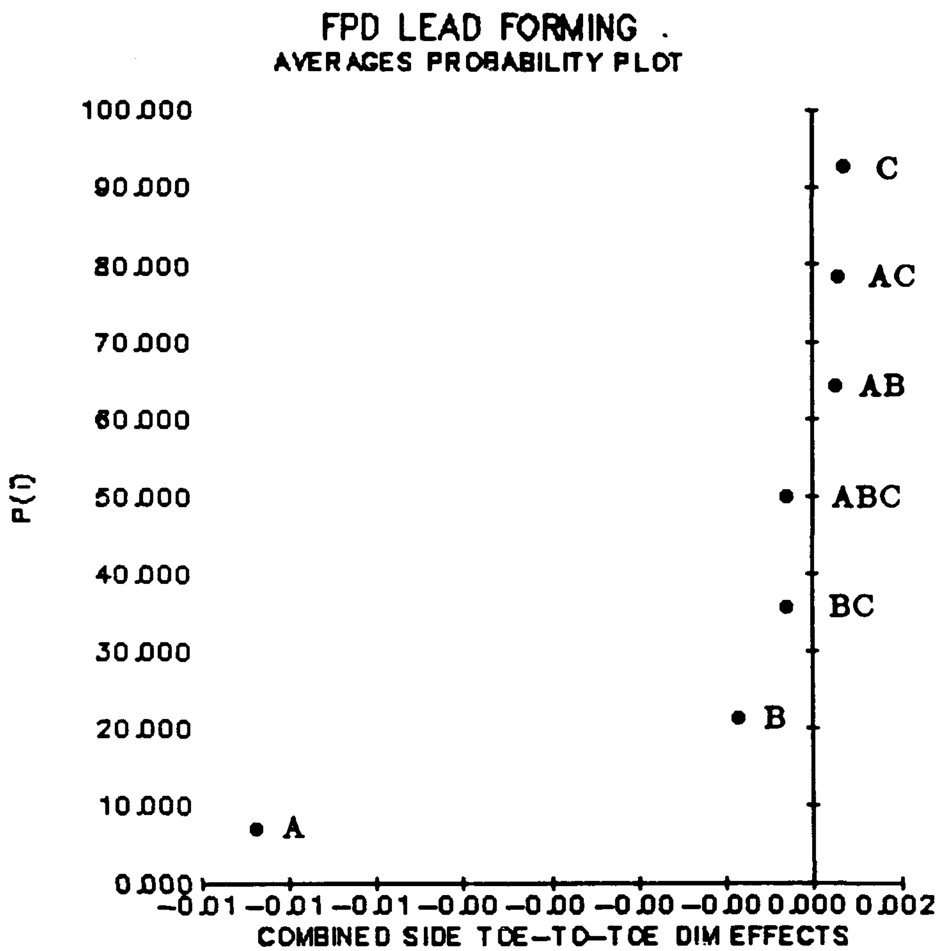

Figure 22. Normal Plot FPD Lead Toe-to-Toe Dimension

Table 53. ANOVA Table FPD Lead Toe-to-Toe Dimension

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PKG STYLE	0.000325	1	0.000325	433.5	0.00	97.3%
2			LEAD THK	0.000004	1	0.000004	6	0.06	1.1%
3		P	LEAD SKEW	0.000001	1	0.000001	NA	NA	0.0%
4		P	ERROR	0.000000	1	0.000000	NA	NA	0.0%
5		P	ERROR	0.000001	1	0.000001	NA	NA	0.0%
6		P	ERROR	0.000000	1	0.000000	NA	NA	0.0%
7		P	ERROR	0.000000	1	0.000000	NA	NA	0.0%
POOLED ERROR:				0.000003	5	0.000000			1.6%
TOTAL(CORRECTED):				0.000333	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 1.22 6 SIGMA ----> 0.0188

Table 54. Cpk Table FPD Lead Toe-to-Toe Dimension

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD TOE-TO-TOE ACROSS SIDES 1.215 TO 1.225, MILS	1.215	1.225	1.221	0.019

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
0.0120	0.5319	0.4255	1.277

2*(USL-X(BAR))	
0.0080	YIELD: 79.87%

2.4.5 Fine Pitch Device Toe Angle

2.4.5.1 Effects

2.4.5.1.1 Analysis. The effects of the three process variables on the response variable, FPD Toe Angle Dimension, are presented in Table 55. Figure 23 is a normal plot of the ranked effects taken from Table 55. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

Table 55. Effects Table, Normal Design FPD Toe Angle Dimension

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Package Style Diacon	Kyocera	B Lead Thickness, mil 5	8	C Lead Skew, mils -3	3	AB **************		AC INTERACTION	AND	BC ERROR	TERMS	ABC **************	
1	-2.030	-2.880	-2.455	-2.455		-2.455		-2.455			-2.455		-2.455		-2.455	-2.455	
2	-2.270	-3.270	-2.770	-2.770		-2.770			-2.770		-2.770	-2.770		-2.770			-2.770
3	0.090	0.110	0.100	0.100			0.100	0.100		0.100			0.100	0.100			0.100
4	-0.040	-2.450	-1.245	-1.245			-1.245		-1.245	-1.245		-1.245			-1.245	-1.245	
5	4.970	4.180	4.575		4.575	4.575		4.575		4.575		4.575			4.575		4.575
6	3.970	4.660	4.315		4.315	4.315			4.315	4.315			4.315	4.315		4.315	
7	4.980	5.530	5.255		5.255		5.255	5.255			5.255	5.255		5.255		5.255	
8	5.330	4.760	5.045		5.045		5.045		5.045		5.045		5.045		5.045		5.045
Total			12.82	-6.37	19.19	3.67	9.16	7.48	5.35	7.75	5.08	5.82	7.01	6.90	5.92	5.87	6.95
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.603	-1.593	4.798	0.916	2.289	1.869	1.336	1.936	1.269	1.454	1.751	1.725	1.480	1.468	1.738
Averages Effect (1<2>-1<1>)				6.390		1.373		-0.533		-0.668		0.298		-0.245		0.270	

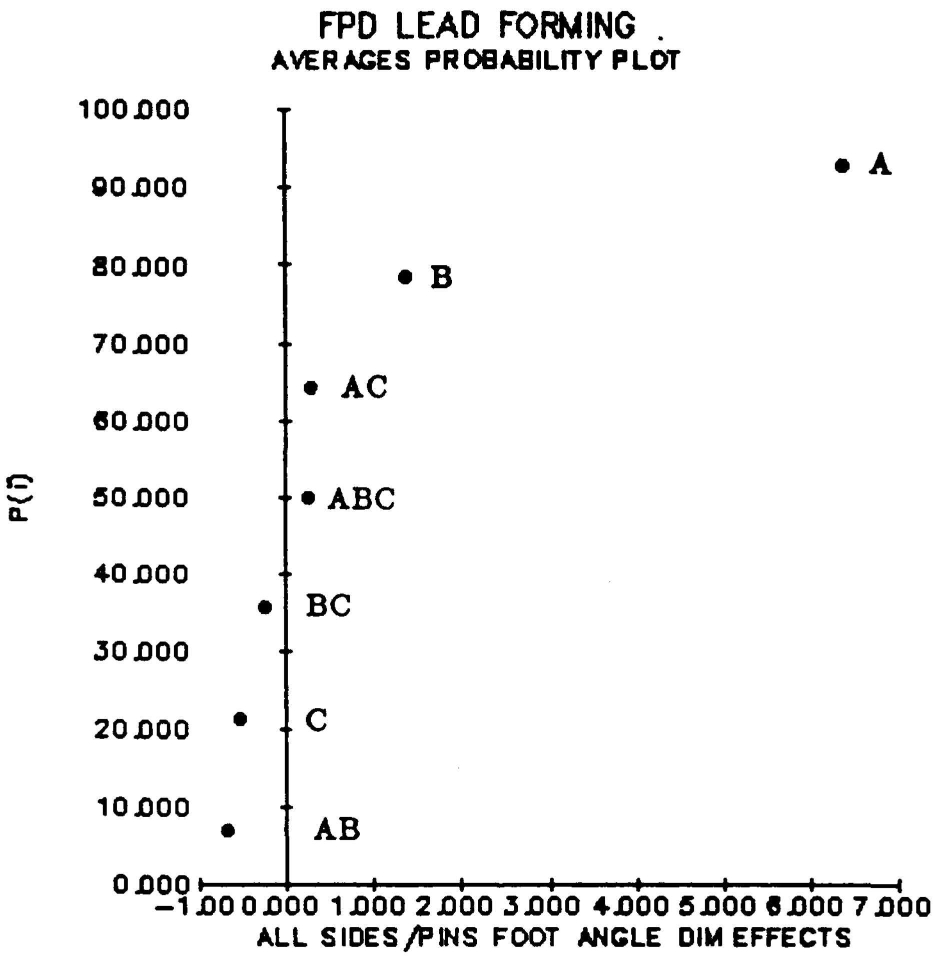

Figure 23. Normal Plot FPD Toe Angle Dimension

2.4.5.2 ANOVA

2.4.5.3 Capability Indices

Tables 56 and 57 present the ANOVA and Cpk/yield data, respectively, for the FPD Toe Angle Dimension response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

Table 56. ANOVA Table FPD Toe Angle Dimension

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PKG STYLE	81.6642	1	81.6642	553.2	0.00	93.3%
2			LEAD THK	3.767512	1	3.767512	25.52	0.01	4.1%
3			LEAD SKEW	0.567112	1	0.567112	3.841	0.14	0.5%
4			ERROR	0.891112	1	0.891112	6.036	0.09	0.9%
5		P	ERROR	0.177012	1	0.177012	NA	NA	0.0%
6		P	ERROR	0.12005	1	0.12005	NA	NA	0.0%
7		P	ERROR	0.1458	1	0.1458	NA	NA	0.0%
POOLED ERROR:				0.442862	3	0.147620			1.2%
TOTAL(CORRECTED):				87.3328	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

Y-BAR : 1.6025 6 SIGMA ----> 9.5715

Table 57. Cpk Table FPD Toe Angle Dimension

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD TOE ANGLE OVERALL -15 TO 15. DEG	-15.000	15.000	1.603	9.572

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
33.2050	3.1343	2.7995	8.398
2*(USL-X(BAR))			
26.7950	YIELD:	100%, ESSENTIALLY	

2.4.5.4 Discussion of Toe Angle Dimension

An examination of the FPD lead toe angle dimension "effects" data in Table 55 indicates that FPD package style has a strong effect on the final package lead toe-to-toe dimension. FPD lead thickness also appears to have a significant effect.

The pattern of the normal plot in Figure 23 strongly supports the data presented in the effects table. The upper right position for the point associated with the package style process variable which places it to the right of the upper end of an imaginary straight line drawing through the remaining points is one of the indicators for non-normal significance. The point associated with the lead thickness variable also lies to the right, but the location is not enough to indicate that its position is due purely to normal random variation. Other points also vary from a straight line, but they do not vary enough to be considered significant.

The data in the ANOVA table for the FPD toe angle dimension, Table 56, provides a stronger indication that the FPD package styles effects are statistically significant. Lead thickness is a much less significant contributor to variability.

The Cpk/yield table, Table 57, demonstrates that this process is in need of improvement. As with the lead skew response, improvement can best be achieved by reducing the "6 sigma" variable, and this can be attacked by eliminating the use of two different package styles in the lead forming die on the Gelzer robot.

2.4.6 Fine Pitch Device Lead Toe Burrs

2.4.6.1 Effects

2.4.6.1.1 Analysis. The effects of the three process variables on the response variable, FPD Toe Angle Dimension, are presented in Table 58. Figure 24 is a normal plot of the ranked effects taken from Table 58. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.4.6.2 ANOVA

2.4.6.3 Capability Indices

Tables 59 and 60 present the ANOVA and Cpk/yield data, respectively, for the FPD Toe Angle Dimension response variable. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.4.6.4 Discussion of Lead Toe Burrs

An examination of the FPD lead toe burr dimension "effects" data in Table 58 indicates that FPD lead thickness has a strong effect on the final package lead toe burr dimension. FPD package style also appears to have a strong significant effect.

The pattern of the normal plot in Figure 24 strongly supports the data presented in the effects table. The upper right position for the points associated with the FPD lead thickness and FPD style process variables, which places it to the right of the upper end of an imaginary straight line drawn through the remaining points, is one of the indicators for non-normal significance. The point associated with the lead skew lies to the left of the lower end of this imaginary straight line, and the location is enough to indicate that its position is due to more than normal random variation. Other points also vary from a straight line, but they do not vary enough to be considered significant.

Table 58. Effects Table, Normal Design FPD Lead Toe Burr

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Package Style Diacon	Kyocera	B Lead Thickness, mils 5	8	C Lead Skew, mils -3	3	AB		AC		BC		ABC	
										*************	INTERACTION	AND	ERROR	TERMS	*************		
1	1.225	1.125	1.175	1.175		1.175		1.175			1.175		1.175		1.175	1.175	
2	1.175	0.950	1.063	1.063		1.063			1.063		1.063	1.063		1.063			1.063
3	1.800	2.725	2.263	2.263			2.263	2.263		2.263			2.263	2.263			2.263
4	1.675	2.300	1.988	1.988			1.988		1.988	1.988		1.988			1.988	1.988	
5	2.225	2.050	2.138		2.138	2.138		2.138		2.138		2.138			2.138		2.138
6	1.700	1.725	1.713		1.713	1.713			1.713	1.713			1.713	1.713		1.713	
7	2.775	3.000	2.888		2.888		2.888	2.888			2.888	2.888		2.888		2.888	
8	3.400	2.675	3.038		3.038		3.038		3.038		3.038		3.038		3.038		3.038
Total			16.26	6.49	9.78	6.09	10.18	8.46	7.80	8.10	8.16	8.08	8.19	7.93	8.34	7.76	8.50
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			2.033	1.622	2.444	1.522	2.544	2.116	1.950	2.025	2.041	2.019	2.047	1.981	2.084	1.941	2.125
Averages Effect (1<2>-1<1>)				0.8219		1.0219		-0.1656		0.0156		0.0281		0.1031		0.1844	

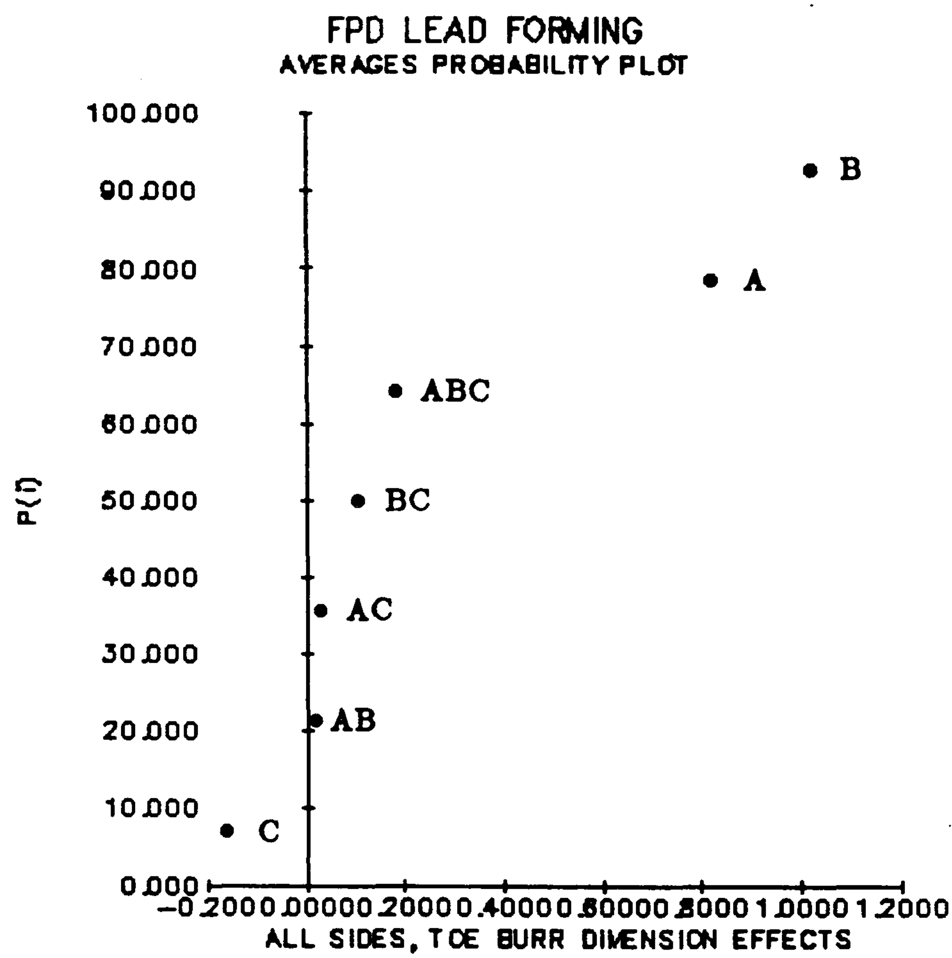

Figure 24. Normal Plot FPD Lead Toe Burr

Table 59. ANOVA Table FPD Lead Toe Burr

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PKG STYLE	1.350957	1	1.350957	69.09	0.00	37.1%
2			LEAD THK	2.088457	1	2.088457	106.8	0.00	57.7%
3		P	LEAD SKEW	0.054863	1	0.054863	NA	NA	0.0%
4		P	ERROR	0.000488	1	0.000488	NA	NA	0.0%
5		P	ERROR	0.001582	1	0.001582	NA	NA	0.0%
6		P	ERROR	0.021269	1	0.021269	NA	NA	0.0%
7			ERROR	0.067988	1	0.067988	3.477	0.13	1.4%
POOLED ERROR:				0.078203	4	0.019550			3.8%
TOTAL(CORRECTED):				3.595605	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 2.0328 6 SIGMA ----> 2.0378

Table 60. Cpk Table FPD Lead Toe Burr

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD TOE BURR OVERALL 0 TO 7 MILS	0.000	7.000	2.033	2.038

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
4.0656	3.4351	4.8751	14.625
2*(USL-X(BAR))			
9.9344	YIELD:	100%, ESSENTIALLY	

The data in the ANOVA table for the FPD toe burrs, Table 59, provides an additional indication that the FPD lead thickness effects, followed by package style effects, are statistically significant. The ANOVA table does not support the normal plot in identifying lead skew as a significant process variable.

The Cpk/yield table, Table 6C, demonstrates that this process is not in imminent need of improvement.

2.4.7 Final Run Process Variables

The final run process variables associated with the FPD lead forming process will reflect the findings of these intermediate experiments. The first change will be to standardize on one FPD package type. This will minimize variability associated with lead coplanarity, toe-to-toe dimension, and lead skew. The lead angle and toe burr variables will not be adversely affected by these changes.

A single point experiment will be run to determine Cpk values for the belly-to-toe dimension. One of the previous problems encountered with this response variable was the measurement of the effect. The microscan profiling instrument, although it had more than acceptable accuracy and precision, did not measure the effect as it is manifested in "real life." The single point experiment will measure the distance from the top of the package to a flat surface, before and after forming, with a surface gage. This technique will average out the standoff provided by the individual leads as happens when the formed part is placed on a PWB. An understanding of the magnitude of this condition is what is desired.

A second single point experiment has been run to gather data for Cpk and yield numbers associated with FPD lead skew. The results will be presented in the final report. The Diacon package was not included in this experiment. Data was collected on NTK packages.

2.5 SUBTASK 5

2.5.1 Experiment 1, Solder Paste Deposit Placement

The details of the solder paste deposit placement experiment are presented in Appendix F of this report. The thrust of the experiment is presented in Figure 25. With the exception of the belly-to-toe response, all of the response data for all of the responses have been collected and reduced and are presented in this report. The FPD belly-to-toe test was not successfully completed. This is explained in this report. A single point experiment was run on the coplanarity response and more meaningful data was collected. This analysis of this rerun is not presented in this report.

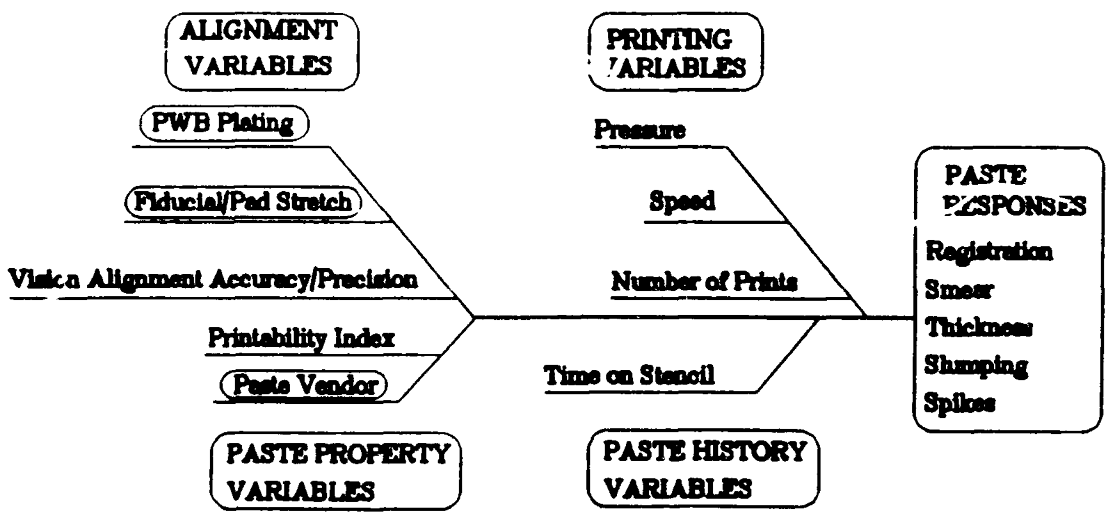

Figure 25. Solder Paste Placement Subtask Cause and Effect Diagram

This subtask involved two 8-run experiments in three process variables. The second experiment was a replicate of the first and was used to determine the variability of the process in addition to the process mean. Since this was a full, factorial design, no reflected runs were required to identify possible interactions between process variables that might have masked assigned process variable effects.

2.5.1.1 Solder Paste Deposit Registration

The data for the solder paste registration response is presented in the following order Misregistration in the upper left corner of the PWB, upper right corner of the PWB, lower left of the PWB, and lower right of the PWB. Misregistration is the resultant of the measured x-axis and y-axis offset. No direction of the offset is presented in this data and analysis.

2.5.1.1.1 Effects

2.5.1.1.1.1 Analysis. The effects of the three process variables on the response variables, Solder Paste Registration upper left corner, upper right corner, lower left corner, and lower right corner, are presented in Tables 61 through 64, respectively. Figures 26 through 29 are the normal plots of the ranked effects taken from Tables 61 through 64, respectively. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.5.1.2 ANOVA

2.5.1.3 Capability Indices

Tables 65 through 68 present the ANOVA data for the Solder Paste Registration response for the upper left, upper right, lower left, and lower right corners of the PWB, respectively. Tables 69 through 72 present the Cpk and yield data for this response variable for the upper left, upper right, lower left, and lower right corners of the PWB, respectively. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.5.1.4 Discussion of Paste Deposit Registration

An examination of the data and analysis for the solder paste registration response variable demonstrate that no process variable consistently appears as having a statistically significant affect on the response. This includes both the normal plots and the ANOVA tables. The only process variable that appears at all is the PWB style variable which appears to be significant for the upper left and upper right PWB corners. The pooled error for these four responses range between 50 percent and 80 percent which tends to indicate that the data is of little significance as far as being able to identify significant variables.

After running the experiments for solder paste placement, it became clear that quantifying the responses is a difficult matter. The measuring tools are sufficiently accurate and precise. The problem is that of defining the physical boundaries of the responses. The paste is an aggregate composed of a fine mesh of Sn63 solder and flux and other organic vehicles. In the case of registration, the best that may be achieved is an improvement in accuracy. Precision within the boundaries of published workmanship standard guidelines appear more to be goals rather than requirements. Actually, the data, analysis, and experience gathered during this experiment indicate that the whole issue of solder paste material and deposition require an engineering study in their own right.

Table 61. Effects Table, Normal Design Solder Paste Registration, Upper Left Corner

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Solder	Paste	Fiducial		PWB		**************INTERACTION AND ERROR TERMS**************							
Trial	Variables			Vendor		Stretch, mils		Style									
No.	Normal	Replic	Avg.	Metech	Multic	0	+3	fused	air								
1	2.162	0.867	1.515	1.515		1.515		1.515			1.515		1.515		1.515	1.515	
2	2.304	0.670	1.487	1.487		1.487			1.487		1.487	1.487		1.487			1.487
3	3.100	0.984	2.042	2.042			2.042	2.042		2.042			2.042	2.042			2.042
4	0.886	1.627	1.257	1.257			1.257		1.257	1.257		1.257			1.257	1.257	
5	1.947	2.412	2.180		2.180	2.180		2.180		2.180		2.180			2.180		2.180
6	1.868	1.282	1.575		1.575	1.575			1.575	1.575			1.575	1.575		1.575	
7	8.823	1.114	4.969		4.969		4.969	4.969			4.969	4.969		4.969		4.969	
8	1.775	0.623	1.199		1.199		1.199		1.199		1.199		1.199		1.199		1.199
Total			16.22	6.30	9.92	6.76	9.47	10.70	5.52	7.05	9.17	9.89	6.33	10.07	6.15	9.31	6.91
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			2.028	1.575	2.481	1.689	2.367	2.676	1.379	1.763	2.292	2.473	1.583	2.518	1.537	2.329	1.727
Averages Effect (1<2>-1<1>)				0.906		0.678		-1.297		0.529		-0.890		-0.981		-0.602	

Table 62. Effects Table, Normal Design Solder Paste Registration, Upper Right Corner

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB		AC		BC		ABC	
										**************INTERACTION AND ERROR TERMS **************							
1	2.985	3.231	3.108	3.108		3.108		3.108			3.108		3.108		3.108	3.108	
2	3.966	1.617	2.792	2.792		2.792			2.792		2.792	2.792		2.792			2.792
3	3.005	2.525	2.765	2.765			2.765	2.765		2.765			2.765	2.765			2.765
4	3.135	1.683	2.409	2.409			2.409		2.409	2.409		2.409			2.409	2.409	
5	2.193	2.611	2.402		2.402	2.402		2.402		2.402		2.402			2.402		2.402
6	1.286	2.247	1.767		1.767	1.767			1.767	1.767			1.767	1.767		1.767	
7	7.553	1.598	4.576		4.576		4.576	4.576			4.576	4.576		4.576		4.576	
8	1.635	3.125	2.380		2.380		2.380		2.380		2.380		2.380		2.380		2.380
Total			22.20	11.07	11.12	10.07	12.13	12.85	9.35	9.34	12.86	12.18	10.02	11.90	10.30	11.86	10.34
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			2.775	2.768	2.781	2.517	3.032	3.213	2.337	2.336	3.214	3.045	2.505	2.975	2.575	2.965	2.585
Averages Effect (1<2>-1<1>)				0.013		0.515		-0.876		0.878		-0.540		-0.400		-0.380	

Table 63. Effects Table, Normal Design Solder Paste Registration, Lower Left Corner

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Solder	Paste	Fiducial		PWB		**************	INTERACTION	AND	ERROR	TERMS	**************		
Trial	Variables			Vendor		Stretch,	mils	Style									
No.	Normal	Replic	Avg.	Metech	Multic	0	±3	fused	air								
1	4.571	4.577	4.574	4.574		4.574		4.574			4.574		4.574		4.574	4.574	
2	4.468	2.269	3.369	3.369		3.369			3.369		3.369	3.369		3.369			3.369
3	0.000	2.340	1.170	1.170			1.170	1.170		1.170			1.170	1.170			1.170
4	3.920	0.657	2.289	2.289			2.289		2.289	2.289		2.289			2.289	2.289	
5	2.590	4.690	3.640		3.640	3.640		3.640		3.640		3.640			3.640		3.640
6	0.920	3.587	2.254		2.254	2.254			2.254	2.254			2.254	2.254		2.254	
7	6.455	0.881	3.668		3.668		3.668	3.668			3.668	3.668		3.668		3.668	
8	1.968	4.067	3.018		3.018		3.018		3.018		3.018		3.018		3.018		3.018
Total			23.98	11.40	12.58	13.84	10.14	13.05	10.93	9.35	14.63	12.97	11.02	10.46	13.52	12.78	11.20
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			2.998	2.850	3.145	3.459	2.536	3.263	2.732	2.338	3.657	3.241	2.754	2.615	3.380	3.196	2.799
Averages Effect (1<2>-1<1>)				0.295		-0.923		-0.531		1.319		-0.488		0.765		-0.397	

Table 64. Effects Table, Normal Design Solder Paste Registration, Lower Right Corner

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB		AC		BC		ABC	
										**************	INTERACTION	AND	ERROR	TERMS	**************		
1	4.820	4.160	4.490	4.490		4.490		4.490			4.490		4.490		4.490	4.490	
2	5.305	2.935	4.120	4.120		4.120			4.120		4.120	4.120		4.120			4.120
3	0.000	3.220	1.610	1.610			1.610	1.610		1.610			1.610	1.610			1.610
4	5.041	4.684	4.863	4.863			4.863		4.863	4.863		4.863			4.863	4.863	
5	3.316	2.903	3.110		3.110	3.110		3.110		3.110		3.110			3.110		3.110
6	2.057	5.330	3.694		3.694	3.694			3.694	3.694			3.694	3.694		3.694	
7	6.642	2.161	4.402		4.402		4.402	4.402			4.402	4.402		4.402		4.402	
8	2.210	4.180	3.195		3.195		3.195		3.195		3.195		3.195		3.195		3.195
Total			29.48	15.08	14.40	15.41	14.07	13.61	15.87	13.28	16.21	16.49	12.99	13.83	15.66	17.45	12.03
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			3.685	3.771	3.600	3.853	3.517	3.403	3.968	3.319	4.052	4.123	3.247	3.456	3.914	4.362	3.009
Averages Effect (1<2>-1<1>)				-0.171		-0.336		0.565		0.733		-0.876		0.458		-1.353	

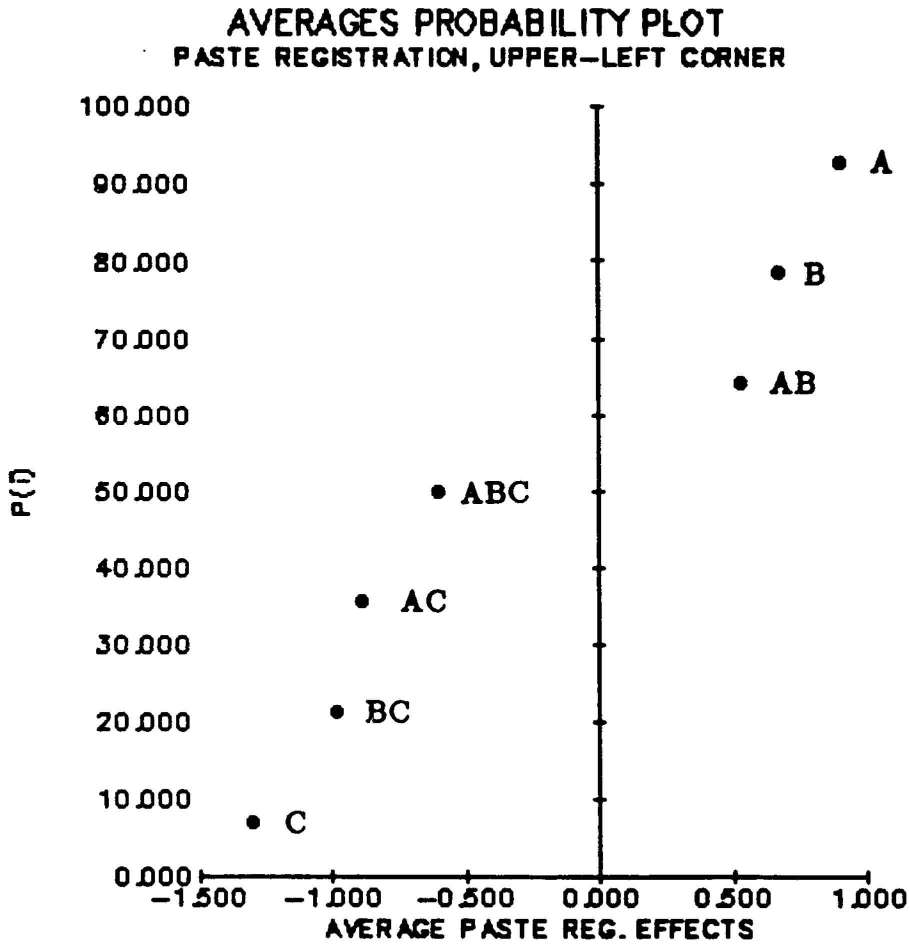

Figure 26. Normal Plot Solder Paste Registration, Upper Left Corner

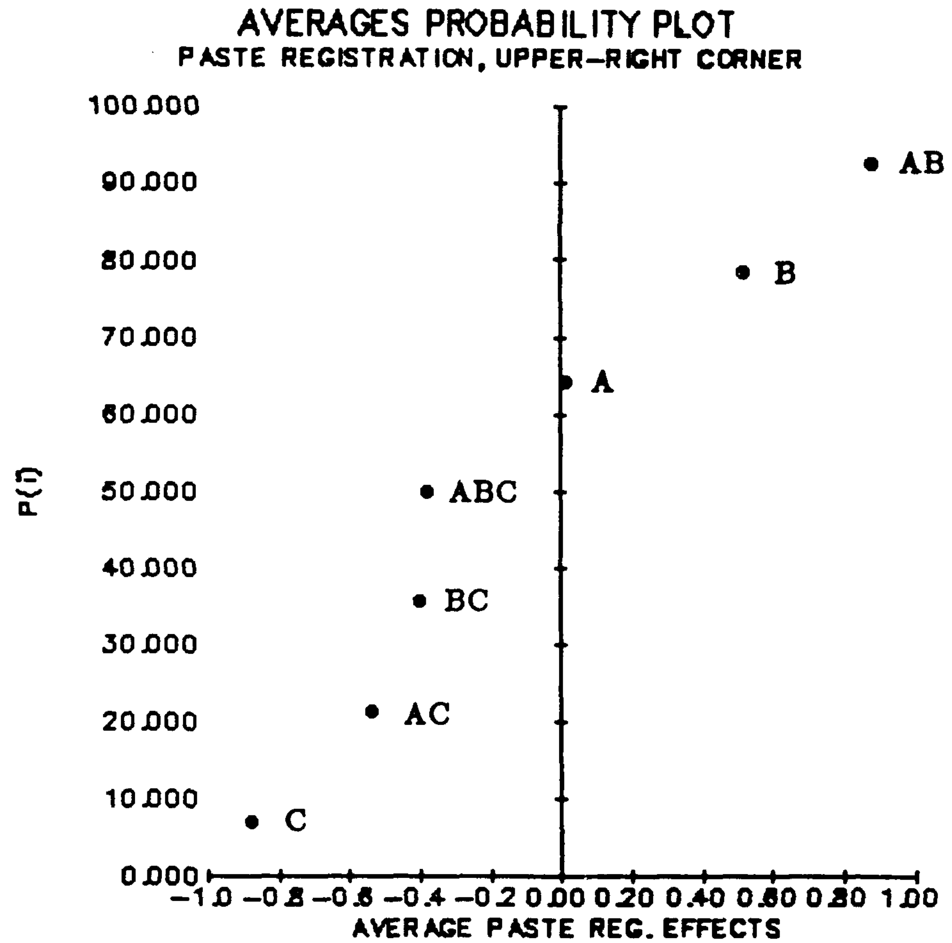

Figure 27. Normal Plot Solder Paste Registration, Upper Right Corner

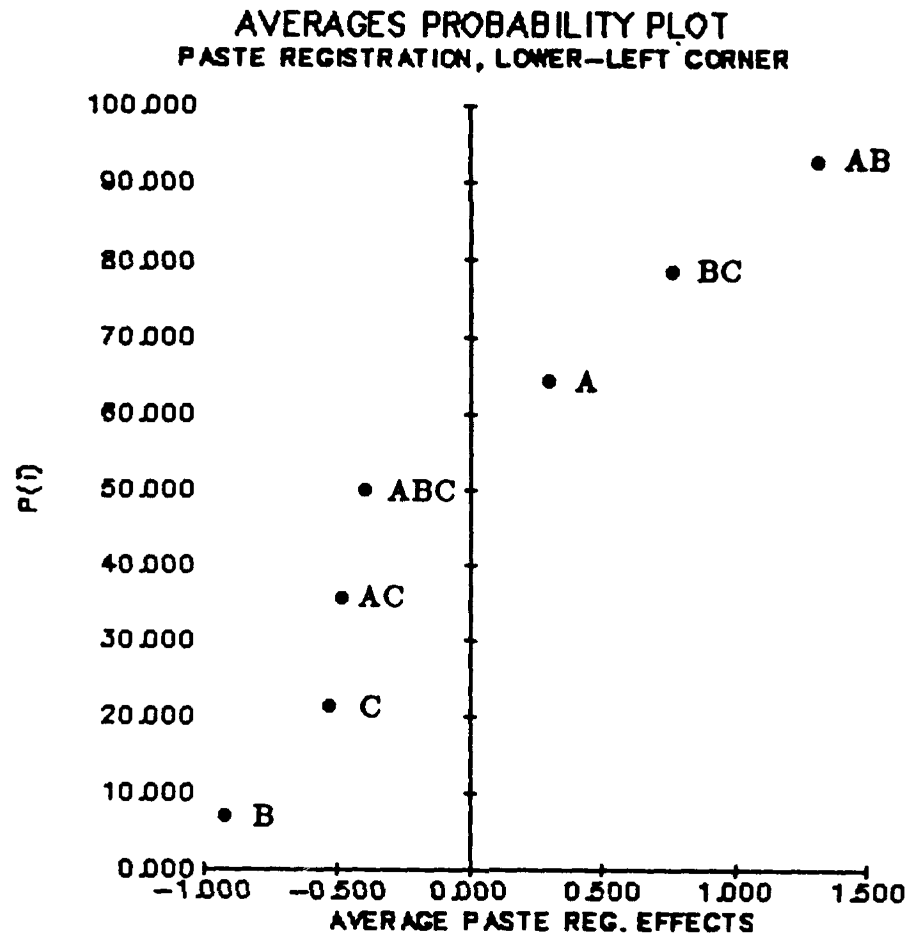

Figure 28. Normal Plot Solder Paste Registration, Lower Left Corner

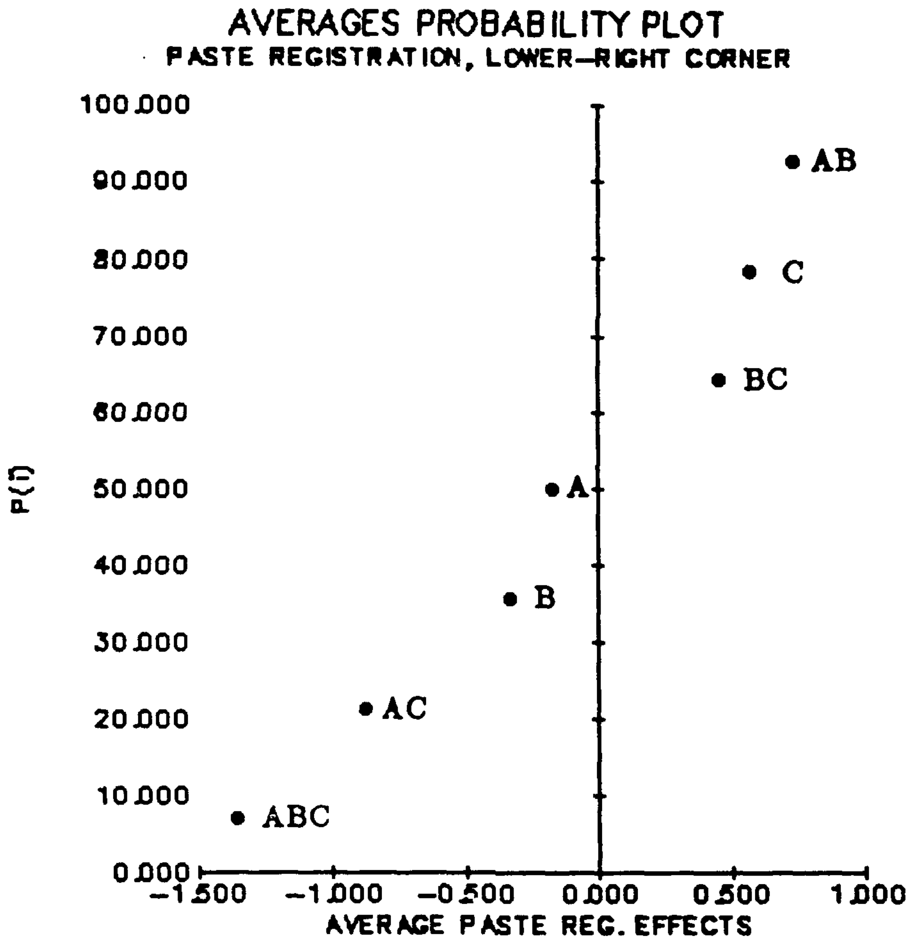

Figure 29. Normal Plot Solder Paste Registration, Lower Right Corner

Table 65. ANOVA Table Solder Paste Registration, Upper Left Corner

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	1.639860	1	1.639860	NA	NA	0.0%
2		P	FID STRET	0.918012	1	0.918012	NA	NA	0.0%
3			PWB STYLE	3.363121	1	3.363121	2.745	0.15	20.0%
4		P	ERROR	0.559682	1	0.559682	NA	NA	0.0%
5		P	ERROR	1.585090	1	1.585090	NA	NA	0.0%
6		P	ERROR	1.923741	1	1.923741	NA	NA	0.0%
7		P	ERROR	0.724206	1	0.724206	NA	NA	0.0%
POOLED ERROR:				7.350592	6	1.225098			80.0%
TOTAL(CORRECTED):				10.71371	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 2.03 6 SIGMA ----> 6.80

Table 66. ANOVA Table Solder Paste Registration, Upper Right Corner

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	0.000318	1	0.000318	NA	NA	0.0%
2		P	FID STRET	0.531222	1	0.531222	NA	NA	0.0%
3			PWB STYLE	1.534314	1	1.534314	4.453	0.09	24.8%
4			ERROR	1.542207	1	1.542207	4.476	0.09	25.0%
5		P	ERROR	0.582390	1	0.582390	NA	NA	0.0%
6		P	ERROR	0.319800	1	0.319800	NA	NA	0.0%
7		P	ERROR	0.288990	1	0.288990	NA	NA	0.0%
POOLED ERROR:				1.722721	5	0.344544			50.3%
TOTAL(CORRECTED):				4.799242	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 2.77 6 SIGMA ----> 3.85

Table 67. ANOVA Table Solder Paste Registration, Lower Left Corner

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	0.173460	1	0.173460	NA	NA	0.0%
2		P	FID STRET	1.703858	1	1.703858	NA	NA	0.0%
3		P	PWB STYLE	0.563922	1	0.563922	NA	NA	0.0%
4			ERROR	3.479522	1	3.479522	4.742	0.07	34.8%
5		P	ERROR	0.475312	1	0.475312	NA	NA	0.0%
6		P	ERROR	1.17045	1	1.17045	NA	NA	0.0%
7		P	ERROR	0.315218	1	0.315218	NA	NA	0.0%
POOLED ERROR:				4.402221	6	0.733703			65.2%
TOTAL(CORRECTED):				7.881743	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 3.00 6 SIGMA ----> 5.40

Table 68. ANOVA Table Solder Paste Registration, Lower Right Corner

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	0.058311	1	0.058311	NA	NA	0.0%
2		P	FID STRET	0.225792	1	0.225792	NA	NA	0.0%
3		P	PWB STYLE	0.63845	1	0.63845	NA	NA	0.0%
4		P	ERROR	1.073845	1	1.073845	NA	NA	0.0%
5		P	ERROR	1.535628	1	1.535628	NA	NA	0.0%
6		P	ERROR	0.419528	1	0.419528	NA	NA	0.0%
7			ERROR	3.662571	1	3.662571	5.561	0.06	39.5%
POOLED ERROR:				3.951554	6	0.658592			60.5%
TOTAL(CORRECTED):				7.614125	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 3.69 6 SIGMA ----> 5.17

Table 69. Cpk Table Solder Paste Registration, Upper Left Corner

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD, 0-4.25	0.000	4.250	2.030	6.800
LCC, 0-7.5	0.000	7.500	2.030	6.800

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
4.0600	0.6250	0.6529	1.959
4.0600	1.1029	1.6088	4.826

2*(USL-X(BAR))	YIELD:
4.4400	94.97%
10.9400	100%, ESSENTIALLY

Table 70. Cpk Table Solder Paste Registration, Upper Right Corner

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD, 0-4.25	0.000	4.250	2.770	3.850
LCC, 0-7.5	0.000	7.500	2.770	3.850

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
5.5400	1.1039	0.7688	2.306
5.5400	1.9481	2.4571	7.371

2*(USL-X(BAR))	YIELD:
2.9600	97.88%
9.4600	100%, ESSENTIALLY

Table 71. Cpk Table Solder Paste Registration, Lower Left Corner

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD, 0-4.25	0.000	4.250	3.000	5.400
LCC, 0-7.5	0.000	7.500	3.000	5.400

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
6.0000	0.7870	0.4630	1.389
6.0000	1.3889	1.6667	5.000

2*(USL-X(BAR))	YIELD:
2.5000	83.51%
9.0000	100%, ESSENTIALLY

Table 72. Cpk Table Solder Paste Registration, Lower Right Corner

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD, 0-4.25	0.000	4.250	3.690	5.170
LCC, 0-7.5	0.000	7.500	3.690	5.170

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
7.3800	0.8221	0.2166	0.650
7.3800	1.4507	1.4739	4.422

2*(USL-X(BAR))	YIELD:
1.1200	48.30%
7.6200	100%, ESSENTIALLY

2.5.2 Solder Paste Deposit Smear

The data for the solder paste smear response is presented in the following order: smear for FPD pads which major axis lies parallel to the major axis of the stencil squeegee, for FPD pads which major axis lies perpendicular to the major axis of the stencil squeegee, for LCC pads which major axis lies parallel to the major axis of the stencil squeegee, and for LCC pads which major axis lies perpendicular to the major axis of the stencil squeegee. Smear is a measure of how far the deposit is dislocated by the influence of stencil motion.

2.5.2.1 Effects

2.5.2.1.1 Analysis. The effects of the three process variables on the response variables, Solder Paste Smear FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular, are presented in Tables 73 through 76, respectively. Figures 30 through 33 are the normal plots of the ranked effects taken from Tables 73 through 76, respectively. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.5.2.2 ANOVA

2.5.2.3 Capability Indices

Tables 77 through 80 present the ANOVA data for the Solder Paste Smear response for the FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular pads, respectively. Tables 81 through 84 present the Cpk and yield data for this response variable for the FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular pads, respectively. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.5.2.4 Discussion of Paste Deposit Smear

An examination of the data and analysis for the solder paste smear response variable, as is the situation with the registration variable, demonstrate that no process variable consistently appears as having a statistically significant affect on the response. This includes both the normal plots and the ANOVA tables. The significance of some of the error terms appears to be as high as some of the process variable terms. The pooled error for these four responses ranges between 33 percent and 48 percent which is not as high as that experienced with the registration response. Nevertheless, there is a suspicion that the data is of little significance as far as being able to identify significant variables.

2.5.3 Solder Paste Deposit Thickness

The data for the solder paste deposit thickness is presented in the following order: thickness for FPD pads which major axis lies parallel to the major axis of the stencil squeegee, for FPD pads which major axis lies perpendicular to the major axis of the stencil squeegee, for LCC pads which major axis lies parallel to the major axis of the stencil squeegee, and for LCC pads which major axis lies perpendicular to the major axis of the stencil squeegee. Thickness is a measure of how far the deposit is dislocated by the influence of stencil motion.

Table 73. Effects Table, Normal Design Solder Paste Smear, FPD Parallel Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch. mils 0	+3	C FWB Style fused	air	AB		AC		BC		ABC	
										**************	INTERACTION	AND	ERROR	TERMS		**************	
1	8.000	8.000	8.000	8.000		8.000		8.000			8.000		8.000		8.000	8.000	
2	1.000	2.000	1.500	1.500		1.500			1.500		1.500	1.500		1.500			1.500
3	4.000	8.000	6.000	6.000			6.000	6.000		6.000			6.000	6.000			6.000
4	8.000	5.000	6.500	6.500			6.500		6.500	6.500		6.500			6.500	6.500	
5	3.000	8.000	5.500		5.500	5.500		5.500		5.500		5.500			5.500		5.500
6	8.000	0.000	4.000		4.000	4.000			4.000	4.000			4.000	4.000		4.000	
7	4.000	4.000	4.000		4.000		4.000	4.000			4.000	4.000		4.000		4.000	
8	3.000	8.000	5.500		5.500		5.500		5.500		5.500		5.500		5.500		5.500
Total			41.00	22.00	19.00	19.00	22.00	23.50	17.50	22.00	19.00	17.50	23.50	15.50	25.50	22.50	18.50
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			5.125	5.500	4.750	4.750	5.500	5.875	4.375	5.500	4.750	4.375	5.875	3.875	6.375	5.625	4.625
Averages Effect (1<2>-1<1>)				-0.750		0.750		-1.500		-0.750		1.500		2.500		-1.000	

Table 74. Effects Table, Normal Design Solder Paste Smear, FPD Perpendicular Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Vendor Metech	Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB		AC		BC		ABC	
										**************	INTERACTION	AND	ERROR	TERMS	**************		
1	8.000	5.000	6.500	6.500		6.500		6.500			6.500		6.500		6.500	6.500	
2	3.000	2.000	2.500	2.500		2.500			2.500		2.500	2.500		2.500			2.500
3	8.000	8.000	8.000	8.000			8.000	8.000		8.000			8.000	8.000			8.000
4	1.000	8.000	4.500	4.500			4.500		4.500	4.500		4.500			4.500	4.500	
5	2.000	3.000	2.500		2.500	2.500		2.500		2.500		2.500			2.500		2.500
6	8.000	1.500	4.750		4.750	4.750			4.750	4.750			4.750	4.750		4.750	
7	8.000	8.000	8.000		8.000		8.000	8.000			8.000	8.000		8.000		8.000	
8	8.000	3.000	5.500		5.500		5.500		5.500		5.500		5.500		5.500		5.500
Total			42.25	21.50	20.75	16.25	26.00	25.00	17.25	19.75	22.50	17.50	24.75	23.25	19.00	23.75	18.50
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			5.281	5.375	5.188	4.063	6.500	6.250	4.313	4.938	5.625	4.375	6.188	5.813	4.750	5.938	4.625
Averages Effect (1(2)-1(1))				-0.188		2.438		-1.938		0.688		1.813		-1.063		-1.313	

Table 75. Effects Table, Normal Design Solder Paste Smear, LCC Parallel Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Vendor Metech	Paste Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB		AC		BC		ABC	
										**************INTERACTION AND ERROR TERMS **************							
1	7.000	5.000	6.000	6.000		6.000		6.000			6.000		6.000		6.000	6.000	
2	16.000	10.000	13.000	13.000		13.000			13.000		13.000	13.000		13.000			13.000
3	16.000	11.000	13.500	13.500			13.500	13.500		13.500			13.500	13.500			13.500
4	16.000	4.000	10.000	10.000			10.000		10.000	10.000		10.000			10.000	10.000	
5	10.000	4.000	7.000		7.000	7.000		7.000		7.000		7.000			7.000		7.000
6	10.000	4.000	7.000		7.000	7.000			7.000	7.000			7.000	7.000		7.000	
7	8.000	6.000	7.000		7.000		7.000	7.000			7.000	7.000		7.000		7.000	
8	15.000	6.000	10.500		10.500		10.500		10.500		10.500		10.500		10.500		10.500
Total			74.00	42.50	31.50	33.00	41.00	33.50	40.50	37.50	36.50	37.00	37.00	40.50	33.50	30.00	44.00
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			9.250	10.625	7.875	8.250	10.250	8.375	10.125	9.375	9.125	9.250	9.250	10.125	8.375	7.500	11.000
Averages Effect (1(2)-1(1))				-2.750		2.000		1.750		-0.250		0.000		-1.750		3.500	

Table 76. Effects Table, Normal Design Solder Paste Smear, LCC Perpendicular Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Vendor Metech	Paste Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB **************	INTERACTION	AC AND	ERROR	BC TERMS	**************	ABC	
1	2.000	2.000	2.000	2.000		2.000		2.000			2.000		2.000		2.000	2.000	
2	2.000	3.000	2.500	2.500		2.500			2.500		2.500	2.500		2.500			2.500
3	4.000	16.000	10.000	10.000			10.000	10.000		10.000			10.000	10.000			10.000
4	4.000	5.000	4.500	4.500			4.500		4.500	4.500		4.500			4.500	4.500	
5	10.000	7.000	8.500		8.500	8.500		8.500		8.500		8.500			8.500		8.500
6	4.000	16.000	10.000		10.000	10.000			10.000	10.000			10.000	10.000		10.000	
7	0.000	5.000	2.500		2.500		2.500	2.500			2.500	2.500		2.500		2.500	
8	8.000	6.000	7.000		7.000		7.000		7.000		7.000		7.000		7.000		7.000
Total			47.00	19.00	28.00	23.00	24.00	23.00	24.00	33.00	14.00	13.00	29.00	25.00	22.00	19.00	28.00
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			5.875	4.750	7.000	5.750	6.000	5.750	6.000	8.250	3.500	4.500	7.250	6.250	5.500	4.750	7.000
Averages Effect (1<2>-1<1>)				2.250		0.250		0.250		-4.750		2.750		-0.750		2.250	

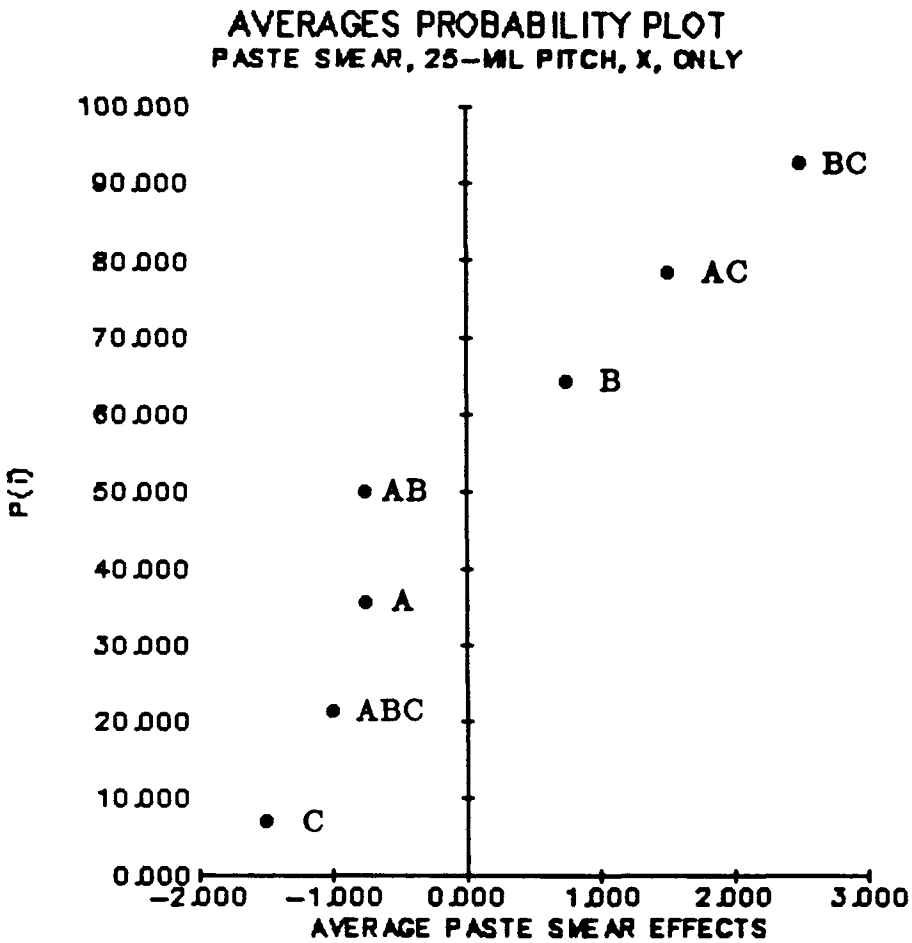

Figure 30. Normal Plot Solder Paste Smear, FPD Parallel Pads

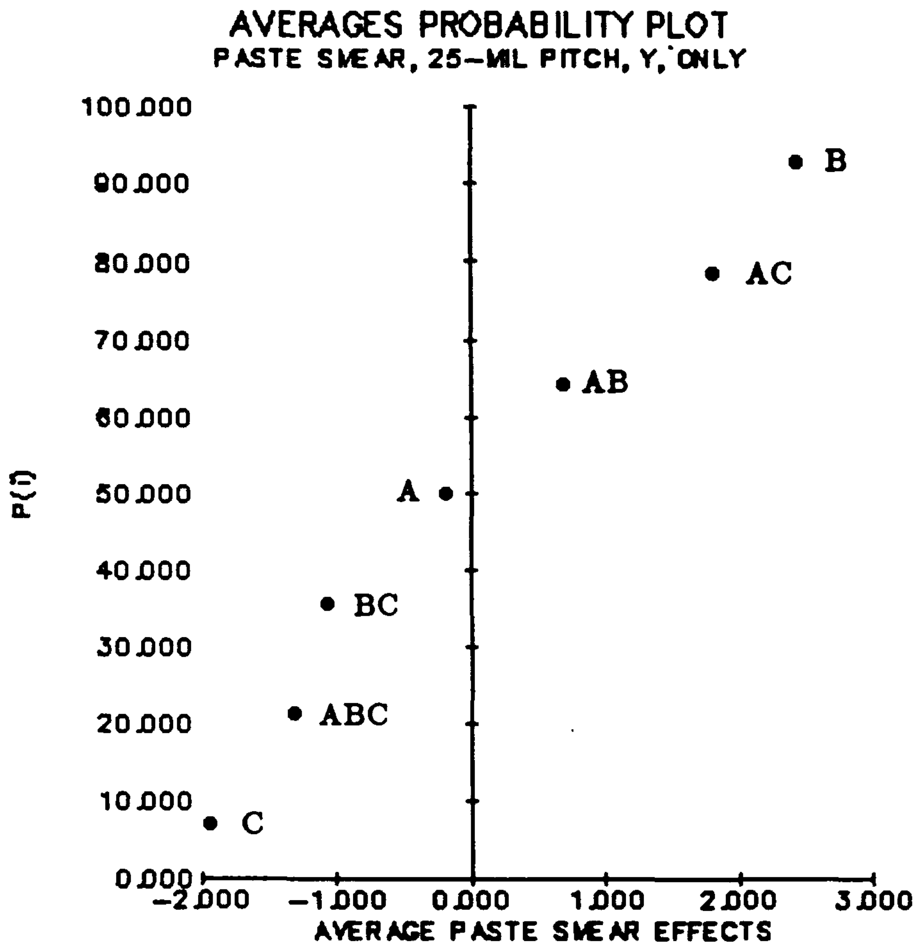

Figure 31. Normal Plot Solder Paste Smear, FPD Perpendicular Pads

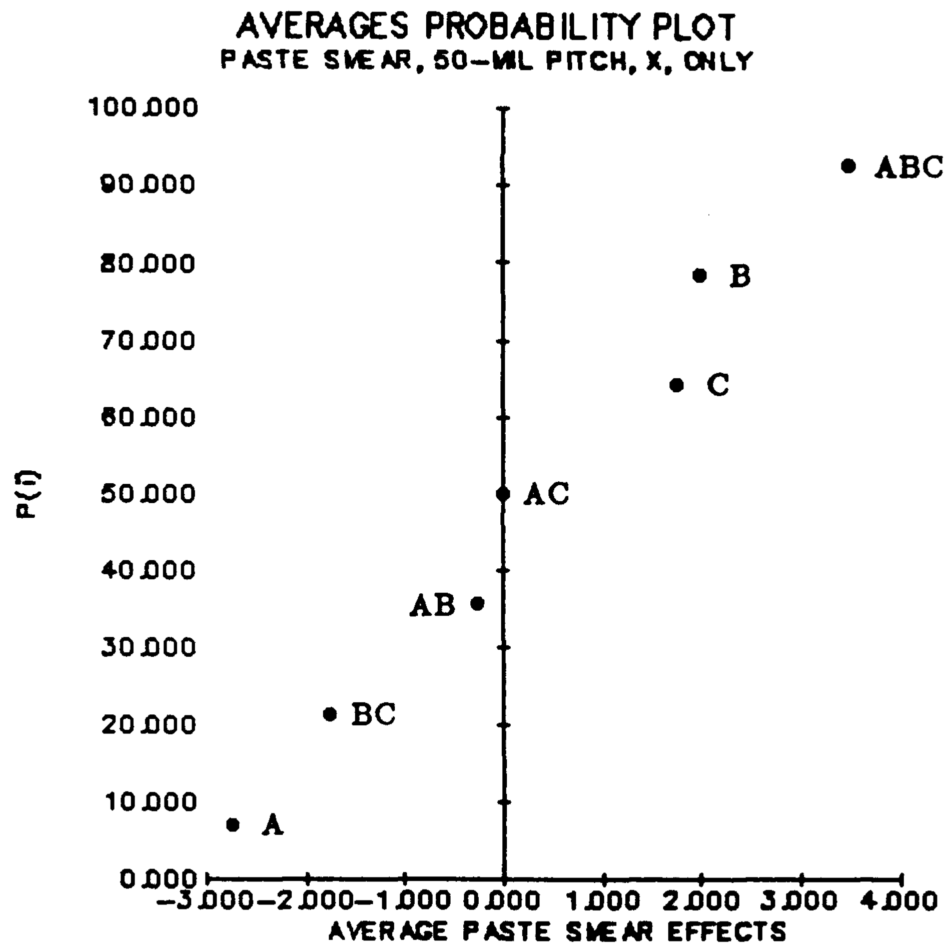

Figure 32. Normal Plot Solder Paste Smear, LCC Parallel Pads

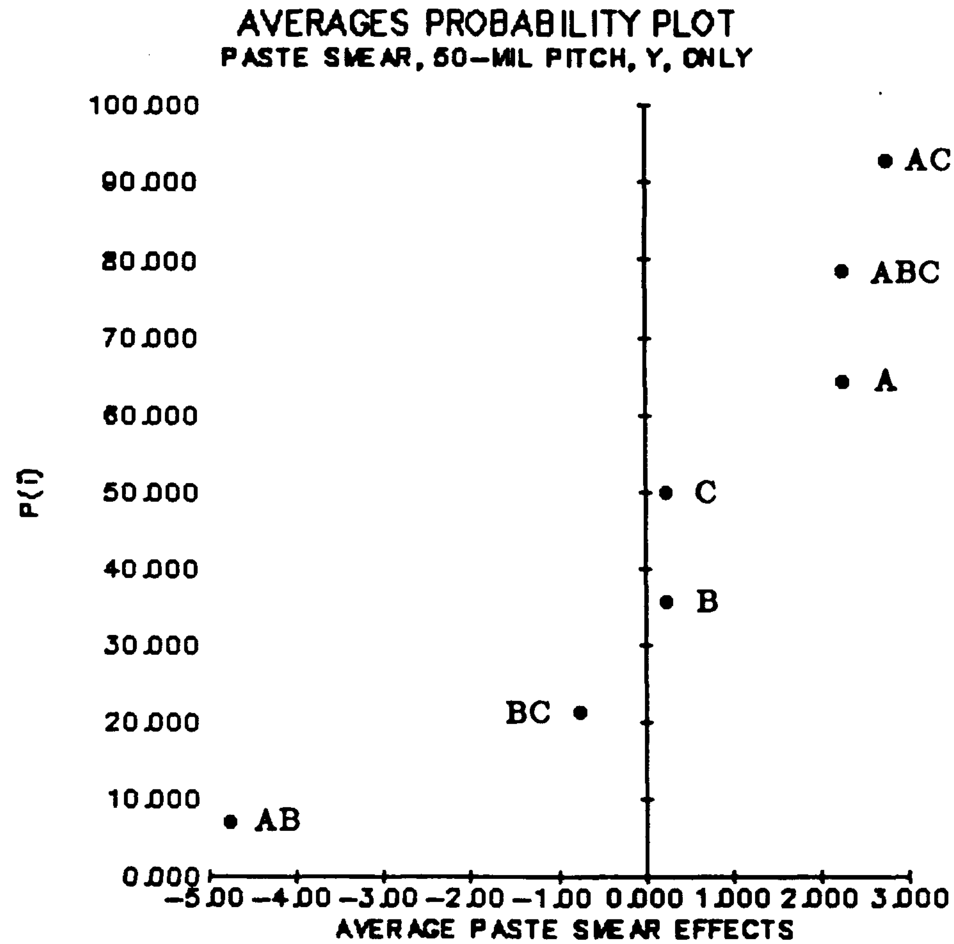

Figure 33. Normal Plot Solder Paste Smear, LCC Perpendicular Pads

Table 77. ANOVA Table Solder Paste Smear, FPD Parallel Pads

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	1.125	1	1.125	NA	NA	0.0%
2		P	FID STRET	1.125	1	1.125	NA	NA	0.0%
3			PWB STYLE	4.5	1	4.5	3.348	0.14	11.7%
4		P	ERROR	1.125	1	1.125	NA	NA	0.0%
5			ERROR	4.5	1	4.5	3.348	0.14	11.7%
6			ERROR	12.5	1	12.5	9.302	0.04	41.5%
7		P	ERROR	2	1	2	NA	NA	0.0%
POOLED ERROR:				5.375	4	1.34375			35.0%
TOTAL(CORRECTED):				26.875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 5.13 6 SIGMA ----> 8.11

Table 78. ANOVA Table Solder Paste Smear, FPD Perpendicular Pads

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	0.125	1	0.125	NA	NA	0.0%
2			FID STRET	12.5	1	12.5	7.843	0.05	33.0%
3			PWB STYLE	8	1	8	5.019	0.09	19.4%
4		P	ERROR	1.125	1	1.125	NA	NA	0.0%
5			ERROR	6.125	1	6.125	3.843	0.12	13.7%
6		P	ERROR	2	1	2	NA	NA	0.0%
7		P	ERROR	3.125	1	3.125	NA	NA	0.0%
POOLED ERROR:				6.375	4	1.59375			33.8%
TOTAL(CORRECTED):				33	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 5.25 6 SIGMA ----> 8.90

Table 79. ANOVA Table Solder Paste Smear, LCC Parallel Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	15.125	1	15.125	3.711	0.11	18.4%
2		P	FID STRET	8	1	8	NA	NA	0.0%
3		P	PWB STYLE	6.125	1	6.125	NA	NA	0.0%
4		P	ERROR	0.125	1	0.125	NA	NA	0.0%
5		P	ERROR	0	1	0	NA	NA	0.0%
6		P	ERROR	6.125	1	6.125	NA	NA	0.0%
7			ERROR	24.5	1	24.5	6.012	0.06	34.0%
POOLED ERROR:				20.375	5	4.075			47.5%
TOTAL(CORRECTED):				60	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 9.25 6 SIGMA ----> 13.35

Table 80. ANOVA Table Solder Paste Smear, LCC Perpendicular Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	10.125	1	10.125	NA	NA	0.0%
2		P	FID STRET	0.125	1	0.125	NA	NA	0.0%
3		P	PWB STYLE	0.125	1	0.125	NA	NA	0.0%
4			ERROR	45.125	1	45.125	10.43	0.02	49.8%
5			ERROR	15.125	1	15.125	3.497	0.12	13.2%
6		P	ERROR	1.125	1	1.125	NA	NA	0.0%
7		P	ERROR	10.125	1	10.125	NA	NA	0.0%
POOLED ERROR:				21.625	5	4.325			37.0%
TOTAL(CORRECTED):				81.875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 5.88 6 SIGMA ----> 14.40

Table 81. Cpk Table Solder Paste Smear, FPD Parallel Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PASTE SMEAR FPD 0-2.5, MILS	0.000	2.500	5.130	8.110

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
10.2600	0.3083	-0.6486	-1.946

2*(USL-X(BAR))	YIELD:
-5.2600	0%, ESSENTIALLY

Table 82. Cpk Table Solder Paste Smear, FPD Perpendicular Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PASTE SMEAR FPD 0-2.5, MILS	0.000	2.500	5.250	8.900

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
10.5000	0.2809	-0.6180	-1.854

2*(USL-X(BAR))	YIELD:
-5.5000	0%, ESSENTIALLY

Table 83. Cpk Table Solder Paste Smear, LCC Parallel Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PASTE SMEAR LCC 0-5. MILS	0.000	5.000	9.250	13.350

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
18.5000	0.3745	-0.6367	-1.910

2*(USL-X(BAR))	YIELD:
-8.5000	0%, ESSENTIALLY

Table 84. Cpk Table Solder Paste Smear, LCC Perpendicular Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PASTE SMEAR LCC 0-5. MILS	0.000	5.000	5.880	14.400

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
11.7600	0.3472	-0.1222	-0.367

2*(USL-X(BAR))	YIELD:
-1.7600	0%, ESSENTIALLY

2.5.3.1 Effects

2.5.3.1.1 Analysis. The effects of the three process variables on the response variables, Solder Paste Thickness FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular, are presented in Tables 85 through 88, respectively. Figures 34 through 37 are the normal plots of the ranked effects taken from Tables 85 through 88, respectively. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.5.3.2 ANOVA

2.5.3.3 Capability Indices

Tables 89 through 92 present the ANOVA data for the Solder Paste Thickness response for the FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular pads, respectively. Tables 93 through 96 present the Cpk and yield data for this response variable for the FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular pads, respectively. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.5.3.4 Discussion of Paste Deposit Thickness

An examination of the data and analysis for the solder paste thickness response variable reveals that the paste vendor and PWB style process variable effects are significant for the FPD pad patterns. This significance applies to both the parallel and perpendicular pad orientations. The levels of significance between these two process variables toggle between the two pad orientations with the PWB style more significant for the parallel orientation and the vendor more significant for the perpendicular orientation. For the LCC pad patterns there appears to be no level of significance for any of the process variables.

The Cpk tables indicate (see Tables 93 and 94) that where the yields are 0 percent (the FPD pads), the problem is associated with the fact that the process mean is not centered. The FPD process requires a lower variability to achieve a satisfactory Cpk than that required for the LCCs because the specification range is much less (2.4 mil versus 4.8 mil). The process can achieve a higher Cpk if the Metech solder paste and fused PWBs are used. An improvement can also be achieved if the stencil thickness is tuned to the solder paste thickness requirements.

2.5.4 Solder Paste Deposit Spikes

The data for the solder paste deposit thickness is presented in the following order: spikes for FPD pads which major axis lies parallel to the major axis of the stencil squeegee, for FPD pads which major axis lies perpendicular to the major axis of the stencil squeegee, for LCC pads which major axis lies parallel to the major axis of the stencil squeegee, and for LCC pads which major axis lies perpendicular to the major axis of the stencil squeegee. Spikes is a measure of how far the deposit is dislocated by the influence of stencil motion.

2.5.4.1 Effects

2.5.4.1.1 Analysis. The effects of the three process variables on the response variables, Solder Paste Spikes FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular, are presented in Tables 97 through 100, respectively. Figures 38 through 41 are the normal plots of the ranked effects taken from Tables 97 through 100, respectively. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

Table 85. Effects Table, Normal Design Solder Paste Thickness FPD, Parallel Pads

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Solder	Paste	Fiducial		PWB									
Trial	Variables			Vendor		Stretch,	mils	Style		**************		INTERACTION	AND ERROR	TERMS		**************	
No.	Normal	Replic	Avg.	Metech	Multic	0	±3	fused	air								
1	8.380	8.100	8.240	8.240		8.240		8.240			8.240		8.240		8.240	8.240	
2	9.260	8.810	9.035	9.035		9.035			9.035		9.035	9.035		9.035			9.035
3	8.900	8.210	8.555	8.555			8.555	8.555		8.555			8.555	8.555			8.555
4	9.050	9.470	9.260	9.260			9.260		9.260	9.260		9.260			9.260	9.260	
5	9.540	8.010	8.775		8.775	8.775		8.775		8.775		8.775			8.775		8.775
6	10.940	9.050	9.995		9.995	9.995			9.995	9.995			9.995	9.995		9.995	
7	8.840	8.900	8.870		8.870		8.870	8.870			8.870	8.870		8.870		8.870	
8	10.580	9.180	9.880		9.880		9.880		9.880		9.880		9.880		9.880		9.880
Total			72.61	35.09	37.52	36.05	36.57	34.44	38.17	36.59	36.03	35.94	36.67	36.46	36.16	36.37	36.25
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			9.076	8.773	9.380	9.011	9.141	8.610	9.543	9.146	9.006	8.985	9.168	9.114	9.039	9.091	9.061
Averages Effect (1<2>-1<1>)				0.607		0.130		0.933		-0.140		0.183		-0.075		-0.030	

Table 86. Effects Table, Normal Design Solder Paste Thickness FPD, Perpendicular Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Vendor Metech	Paste Multic	B Fiducial Stretch. 0	mils +3	C PWB Style fused	air	AB	************** INTERACTION	AC	AND	BC	ERROR TERMS	ABC	**************
1	6.850	7.590	7.220	7.220		7.220		7.220			7.220		7.220		7.220	7.220	
2	7.670	6.760	7.215	7.215		7.215			7.215		7.215	7.215		7.215			7.215
3	6.690	6.790	6.740	6.740			6.740	6.740		6.740			6.740	6.740			6.740
4	7.290	7.810	7.550	7.550			7.550		7.550	7.550		7.550			7.550	7.550	
5	8.640	7.790	8.215		8.215	8.215		8.215		8.215		8.215			8.215		8.215
6	10.330	9.290	9.810		9.810	9.810			9.810	9.810			9.810	9.810		9.810	
7	6.970	8.050	7.510		7.510		7.510	7.510			7.510	7.510		7.510		7.510	
8	10.220	8.260	9.240		9.240		9.240		9.240		9.240		9.240		9.240		9.240
Total			63.50	28.73	34.78	32.46	31.04	29.69	33.82	32.32	31.19	30.49	33.01	31.28	32.23	32.09	31.41
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			7.938	7.181	8.694	8.115	7.760	7.421	8.454	8.079	7.796	7.623	8.253	7.819	8.056	8.023	7.853
Averages Effect (1<2>-1<1>)				1.513		-0.355		1.032		-0.282		0.630		0.238		-0.170	

Table 87. Effects Table, Normal Design Solder Paste Thickness, LCC Parallel Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Vendor Metech	Paste Multic	B Fiducial Stretch, mils 0	±3	C PWB Style fused	air	AB (INTERACTION AND ERROR TERMS)		AC		BC		ABC	
1	13.480	13.070	13.275	13.275		13.275		13.275			13.275		13.275		13.275	13.275	
2	13.290	12.540	12.915	12.915		12.915			12.915		12.915	12.915		12.915			12.915
3	12.070	12.900	12.485	12.485			12.485	12.485		12.485			12.485	12.485			12.485
4	13.240	12.460	12.850	12.850			12.850		12.850	12.850		12.850			12.850	12.850	
5	13.470	12.460	12.965		12.965	12.965		12.965		12.965		12.965			12.965		12.965
6	14.800	13.600	14.200		14.200	14.200			14.200	14.200			14.200	14.200		14.200	
7	12.670	13.050	12.860		12.860		12.860	12.860			12.860	12.860		12.860		12.860	
8	14.000	13.070	13.535		13.535		13.535		13.535		13.535		13.535		13.535		13.535
Total			105.09	51.53	53.56	53.36	51.73	51.59	53.50	52.50	52.59	51.59	53.49	52.46	52.63	53.19	51.90
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			13.136	12.881	13.390	13.339	12.933	12.896	13.375	13.125	13.146	12.898	13.374	13.115	13.156	13.296	12.975
Averages Effect (1<2>-1<1>)				0.509		-0.406		0.479		0.021		0.476		0.041		-0.321	

Table 88. Effects Table, Normal Design Solder Paste Thickness, LCC Perpendicular Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Vendor Metech	Paste Multic	B Fiducial Stretch, 0	mils ±3	C PWB Style fused	air	AB	***INTERACTION	AC	AND ERROR	BC	TERMS***	ABC	
1	10.660	11.190	10.925	10.925		10.925		10.925			10.925		10.925		10.925	10.925	
2	11.270	10.510	10.890	10.890		10.890			10.890		10.890	10.890		10.890			10.890
3	9.770	10.770	10.270	10.270			10.270	10.270		10.270			10.270	10.270			10.270
4	11.300	10.610	10.955	10.955			10.955		10.955	10.955		10.955			10.955	10.955	
5	12.540	11.800	12.170		12.170	12.170		12.170		12.170		12.170			12.170		12.170
6	12.810	12.700	12.755		12.755	12.755			12.755	12.755			12.755	12.755		12.755	
7	11.390	11.620	11.505		11.505		11.505	11.505			11.505	11.505		11.505		11.505	
8	13.130	11.890	12.510		12.510		12.510		12.510		12.510		12.510		12.510		12.510
Total			91.98	43.04	48.94	46.74	45.24	44.87	47.11	46.15	45.83	45.52	46.46	45.42	46.56	46.14	45.84
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			11.498	10.760	12.235	11.685	11.310	11.218	11.778	11.538	11.458	11.380	11.615	11.355	11.640	11.535	11.460
Averages Effect (1<2>-1<1>)				1.475		-0.375		0.560		-0.080		0.235		0.285		-0.075	

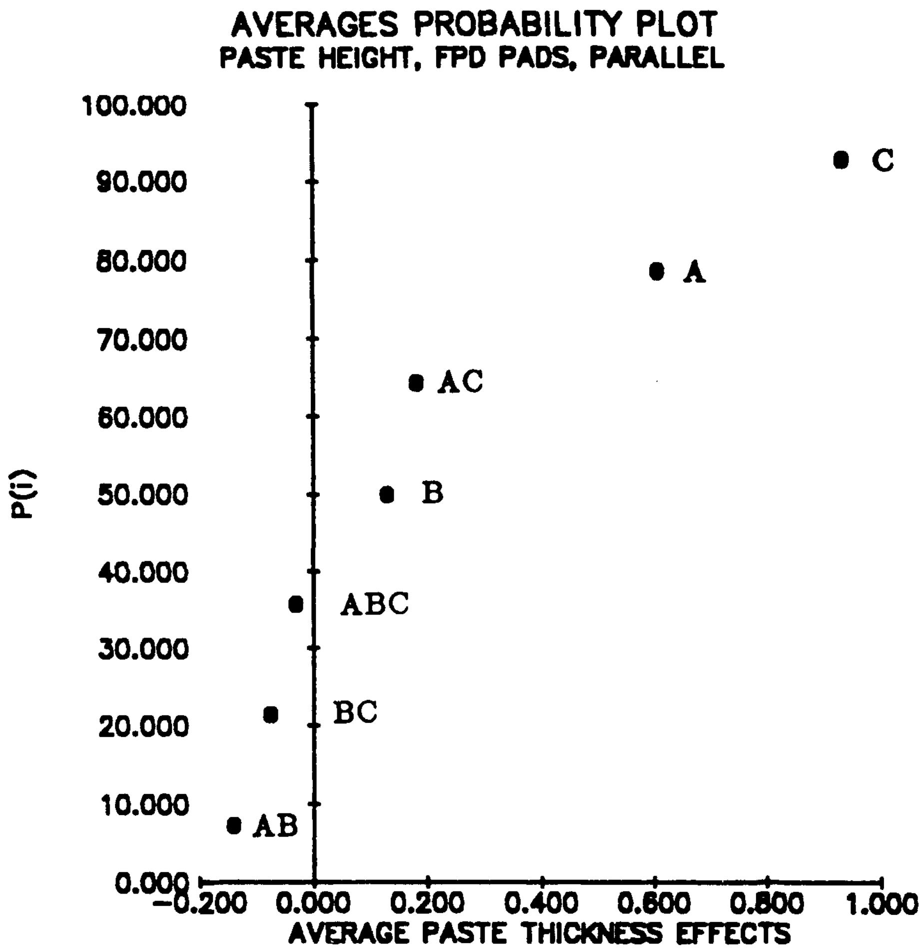

Figure 34. Normal Plot Solder Paste Thickness, FPD Parallel Pads

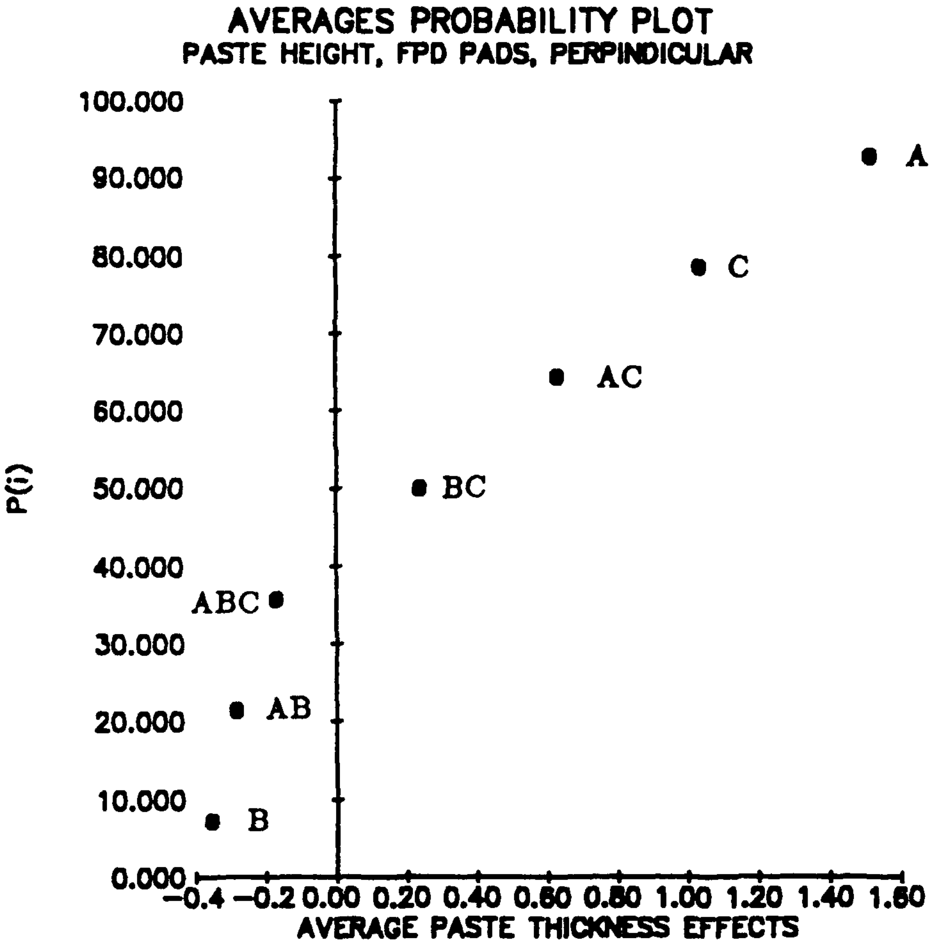

Figure 35. Normal Plot Solder Paste Thickness, FPD Perpendicular Pads

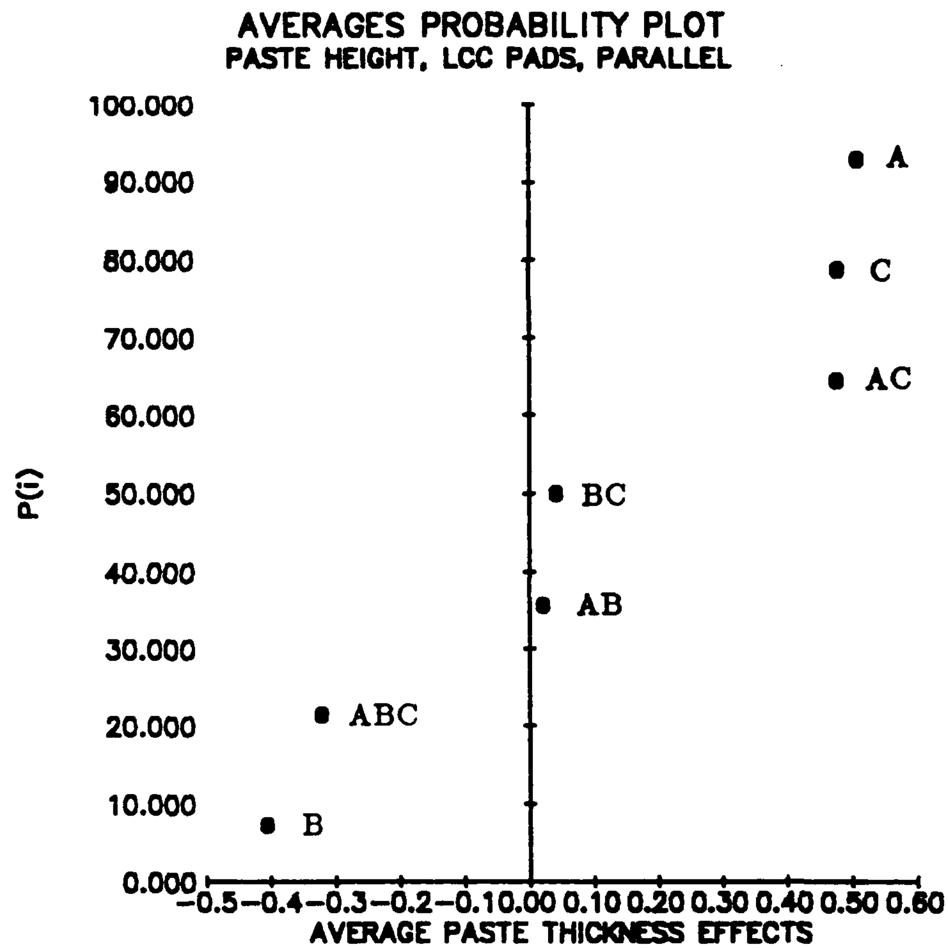

Figure 36. Normal Plot Solder Paste Thickness, LCC Parallel Pads

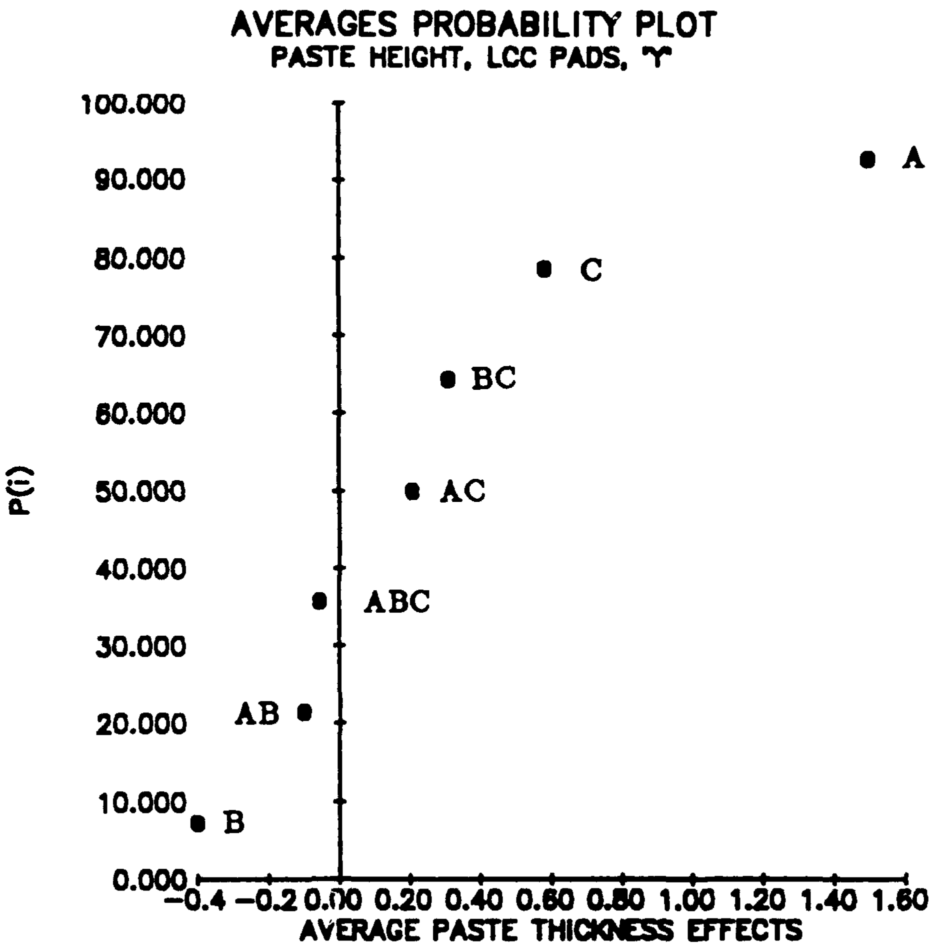

Figure 37. Normal Plot Solder Paste Thickness, LCC Perpendicular Pads

Table 89. ANOVA Table Solder Paste Thickness, FPD Parallel Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	0.741153	1	0.741153	24.67	0.00	27.0%
2		P	FID STRET	0.033153	1	0.033153	NA	NA	0.0%
3			PWR STYLE	1.743778	1	1.743778	58.05	0.00	65.0%
4		P	ERROR	0.038503	1	0.038503	NA	NA	0.0%
5		P	ERROR	0.065703	1	0.065703	NA	NA	0.0%
6		P	ERROR	0.010878	1	0.010878	NA	NA	0.0%
7		P	ERRO	0.001953	1	0.001953	NA	NA	0.0%
POOLED ERROR:				0.150190	5	0.030038			8.0%
TOTAL (CORRECTED):				2.635121	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 9.08 6 SIGMA ----> 1.87

Table 90. ANOVA Table Solder Paste Thickness, FPD Perpendicular Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	4.575312	1	4.575312	31.43	0.01	54.8%
2		P	FID STRET	0.25205	1	0.25205	NA	NA	0.0%
3			PWR STYLE	2.132112	1	2.132112	14.64	0.02	24.6%
4		P	ERROR	0.159612	1	0.159612	NA	NA	0.0%
5			ERROR	0.7938	1	0.7938	5.453	0.08	8.0%
6		P	ERROR	0.112812	1	0.112812	NA	NA	0.0%
7		P	ERROR	0.0578	1	0.0578	NA	NA	0.0%
POOLED ERROR:				0.582275	4	0.145568			12.6%
TOTAL (CORRECTED):				8.0835	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 7.34 6 SIGMA ----> 3.51

Table 91. ANOVA Table Solder Paste Thickness, LCC Parallel Pads

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	0.517653	1	0.517653	240.4	0.00	26.2%
2			FID STRET	0.330078	1	0.330078	153.3	0.00	16.6%
3			PWB STYLE	0.458403	1	0.458403	212.9	0.00	23.2%
4		P	ERROR	0.000903	1	0.000903	NA	NA	0.0%
5			ERROR	0.453628	1	0.453628	210.6	0.00	22.9%
6		P	ERROR	0.003403	1	0.003403	NA	NA	0.0%
7			ERROR	0.206403	1	0.206403	95.86	0.01	10.4%
POOLED ERROR:				0.004306	2	0.002153			0.8%
TOTAL(CORRECTED):				1.970471	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 13.14 6 SIGMA ----> 1.43

Table 92. ANOVA Table Solder Paste Thickness, LCC Perpendicular Pads

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	4.35125	1	4.35125	97.05	0.00	77.5%
2			FID STRET	0.28125	1	0.28125	6.273	0.09	4.3%
3			PWB STYLE	0.6272	1	0.6272	13.98	0.03	10.5%
4		P	ERROR	0.0128	1	0.0128	NA	NA	0.0%
5		P	ERROR	0.11045	1	0.11045	NA	NA	0.0%
6			ERROR	0.16245	1	0.16245	3.623	0.15	2.1%
7		P	ERROR	0.01125	1	0.01125	NA	NA	0.0%
POOLED ERROR:				0.1345	3	0.044833			5.6%
TOTAL(CORRECTED):				5.55665	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 11.50 6 SIGMA ----> 2.62

Table 93. Cpk Table Solder Paste Thickness, FPD Parallel Pads

```
RESP          SPEC LIMIT
VAR           LOWER    UPPER    X(BAR)  6 SIGMA(total) TERM

PAST THICK    4.800    7.200    9.080         1.870
4.8-7.2. MILS

                                         PROCESS
2*(X(BAR)-LSL)        CP      CPK        SIGMA
    8.5600         1.2834  -2.0107      -6.032

2*(USL-X(BAR))      YIELD:
   -3.7600         0%. ESSENTIALLY
```

Table 94. Cpk Table Solder Paste Thickness, FPD Perpendicular Pads

```
RESP          SPEC LIMIT
VAR           LOWER    UPPER    X(BAR)  6 SIGMA(total) TERM

PAST THICK    4.800    7.200    7.940         3.510
4.8-7.2. MILS

                                         PROCESS
2*(X(BAR)-LSL)        CP      CPK        SIGMA
    6.2800         0.6838  -0.4217      -1.265

2*(USL-X(BAR))      YIELD:
   -1.4800         0%. ESSENTIALLY
```

Table 95. Cpk Table Solder Paste Thickness, LCC Parallel Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PAST THICK 9.6-14.4, MILS	9.600	14.400	13.140	1.430

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
7.0800	3.3566	1.7622	5.287

2*(USL-X(BAR))	YIELD:
2.5200	100%, ESSENTIALLY

Table 96. Cpk Table Solder Paste Thickness, LCC Perpendicular Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
PAST THICK 9.6-14.4, MILS	9.600	14.400	11.500	2.620

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
3.8000	1.8321	2.2137	6.641

2*(USL-X(BAR))	YIELD:
5.8000	100%, ESSENTIALLY

Table 97. Effects Table, Normal Design Solder Paste Spikes, FPD Parallel Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB	***INTERACTION	AC	AND	BC	ERROR	ABC TERMS	***
1	4.700	5.300	5.000	5.000		5.000		5.000			5.000		5.000		5.000	5.000	
2	4.800	6.700	5.750	5.750		5.750			5.750		5.750	5.750		5.750			5.750
3	6.900	3.400	5.150	5.150			5.150	5.150		5.150			5.150	5.150			5.150
4	3.800	8.100	5.950	5.950			5.950		5.950	5.950		5.950			5.950	5.950	
5	2.800	3.200	3.000		3.000	3.000		3.000		3.000		3.000			3.000		3.000
6	5.400	2.800	4.100		4.100	4.100			4.100	4.100			4.100	4.100		4.100	
7	1.900	2.900	2.400		2.400		2.400	2.400			2.400	2.400		2.400		2.400	
8	6.700	2.800	4.750		4.750		4.750		4.750		4.750		4.750		4.750		4.750
Total			36.10	21.85	14.25	17.85	18.25	15.55	20.55	18.20	17.90	17.10	19.00	17.40	18.70	17.45	18.65
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			4.513	5.463	3.563	4.463	4.563	3.888	5.138	4.550	4.475	4.275	4.750	4.350	4.675	4.363	4.663
Averages Effect (1<2>-1<1>)				-1.900		0.100		1.250		-0.075		0.475		0.325		0.300	

Table 98. Effects Table, Normal Design Solder Paste Spikes, FPD Perpendicular Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch, mils 0	±3	C PWB Style fused	air	AB	********INTERACTION	AC	AND	BC	ERROR TERMS	ABC	********
1	6.100	12.500	9.300	9.300		9.300		9.300			9.300		9.300		9.300	9.300	
2	8.300	12.800	10.550	10.550		10.550			10.550		10.550	10.550		10.550			10.550
3	9.400	6.800	8.100	8.100			8.100	8.100		8.100			8.100	8.100			8.100
4	5.600	8.300	6.950	6.950			6.950		6.950	6.950		6.950			6.950	6.950	
5	5.200	3.100	4.150		4.150	4.150		4.150		4.150		4.150			4.150		4.150
6	4.700	4.700	4.700		4.700	4.700			4.700	4.700			4.700	4.700		4.700	
7	5.600	5.200	5.400		5.400		5.400	5.400			5.400	5.400		5.400		5.400	
8	4.800	5.200	5.000		5.000		5.000		5.000		5.000		5.000		5.000		5.000
Total			54.15	34.90	19.25	28.70	25.45	26.95	27.20	23.90	30.25	27.05	27.10	28.75	25.40	26.35	27.80
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			6.769	8.725	4.813	7.175	6.363	6.737	6.800	5.975	7.563	6.763	6.775	7.188	6.350	6.588	6.950
Averages Effect (1<2>-1<1>)				-3.913		-0.812		0.063		1.587		0.013		-0.838		0.362	

Table 99. Effects Table, Normal Design Solder Paste Spikes, LCC Parallel Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch, mils 0	±3	C PWB Style fused	air	AB		AC		BC		ABC	
										**************	INTERACTION	AND	ERROR	TERMS	**************		
1	11.100	13.700	12.400	12.400		12.400		12.400			12.400		12.400		12.400	12.400	
2	10.100	8.300	9.200	9.200		9.200			9.200		9.200	9.200		9.200			9.200
3	8.300	8.100	8.200	8.200			8.200	8.200		8.200			8.200	8.200			8.200
4	8.900	16.000	12.450	12.450			12.450		12.450	12.450		12.450			12.450	12.450	
5	4.300	8.000	6.150		6.150	6.150		6.150		6.150		6.150			6.150		6.150
6	7.300	9.800	8.550		8.550	8.550			8.550	8.550			8.550	8.550		8.550	
7	3.200	5.600	4.400		4.400		4.400	4.400			4.400	4.400		4.400		4.400	
8	8.100	10.500	9.300		9.300		9.300		9.300		9.300		9.300		9.300		9.300
Total			70.65	42.25	28.40	36.30	34.35	31.15	39.50	35.35	35.30	32.20	38.45	30.35	40.30	37.80	32.85
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			8.831	10.563	7.100	9.075	8.588	7.788	9.875	8.838	8.825	8.050	9.613	7.588	10.075	9.450	8.213
Averages Effect (1<2>-1<1>)				-3.462		-0.488		2.088		-0.012		1.563		2.487		-1.238	

Table 100. Effects Table, Normal Design Solder Paste Spikes, LCC Perpendicular Pads

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Solder Paste Vendor Metech	Multic	B Fiducial Stretch, mils 0	+3	C PWB Style fused	air	AB		AC		BC		ABC	
										************** INTERACTION AND ERROR TERMS **************							
1	8.500	13.000	10.750	10.750		10.750		10.750			10.750		10.750		10.750	10.750	
2	10.900	9.200	10.050	10.050		10.050			10.050		10.050	10.050		10.050			10.050
3	16.000	8.500	12.250	12.250			12.250	12.250		12.250			12.250	12.250			12.250
4	13.300	12.200	12.750	12.750			12.750		12.750	12.750		12.750			12.750	12.750	
5	5.200	9.800	7.500		7.500	7.500		7.500		7.500		7.500			7.500		7.500
6	10.400	10.000	10.200		10.200	10.200			10.200	10.200			10.200	10.200		10.200	
7	9.600	13.600	11.600		11.600		11.600	11.600			11.600	11.600		11.600		11.600	
8	11.500	9.700	10.600		10.600		10.600		10.600		10.600		10.600		10.600		10.600
Total			85.70	45.80	39.90	38.50	47.20	42.10	43.60	42.70	43.00	41.90	43.80	44.10	41.60	45.30	40.40
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			10.713	11.450	9.975	9.625	11.800	10.525	10.900	10.675	10.750	10.475	10.950	11.025	10.400	11.325	10.100
Averages Effect (1<2>-1<1>)				-1.475		2.175		0.375		0.075		0.475		-0.625		-1.225	

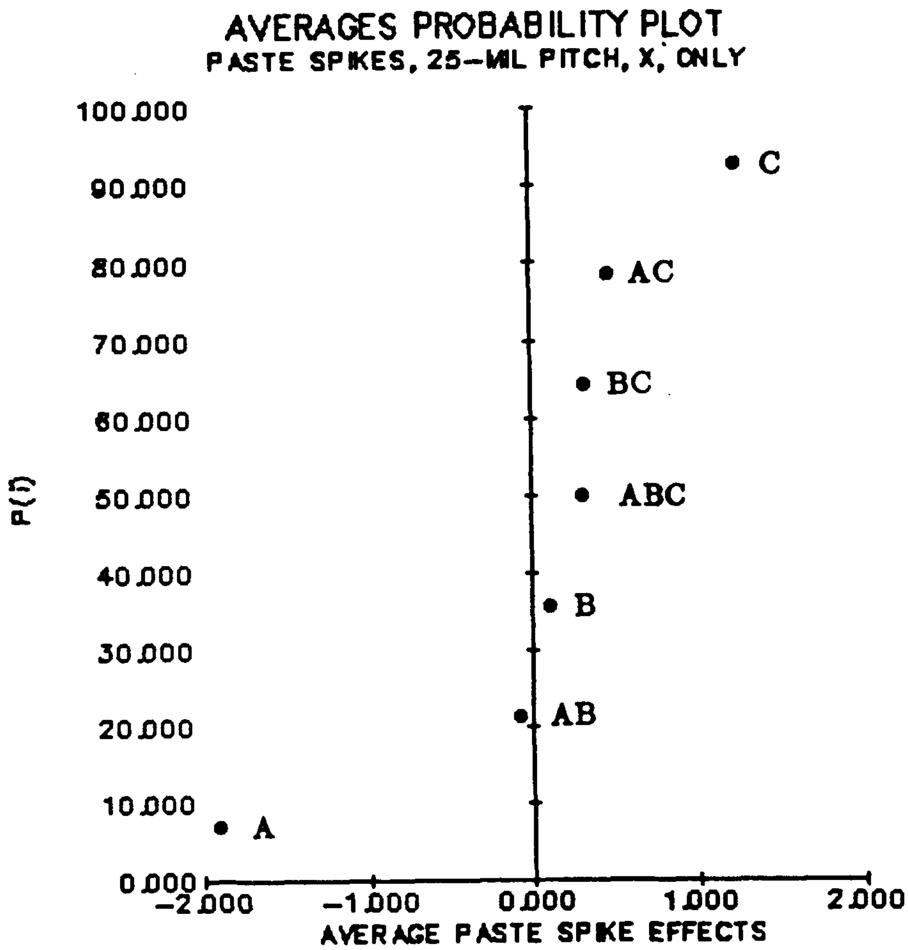

Figure 38. Normal Plot Solder Paste Spikes, FPD Parallel Pads

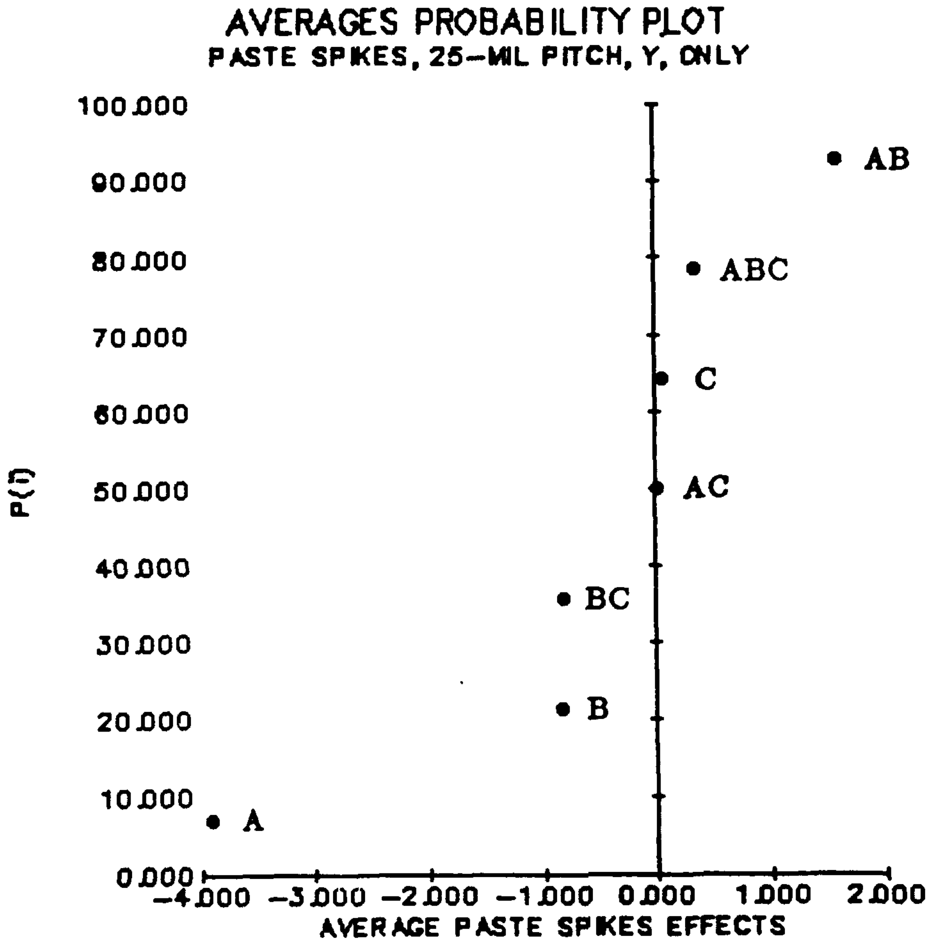

Figure 39. Normal Plot Solder Paste Spikes, FPD Perpendicular Pads

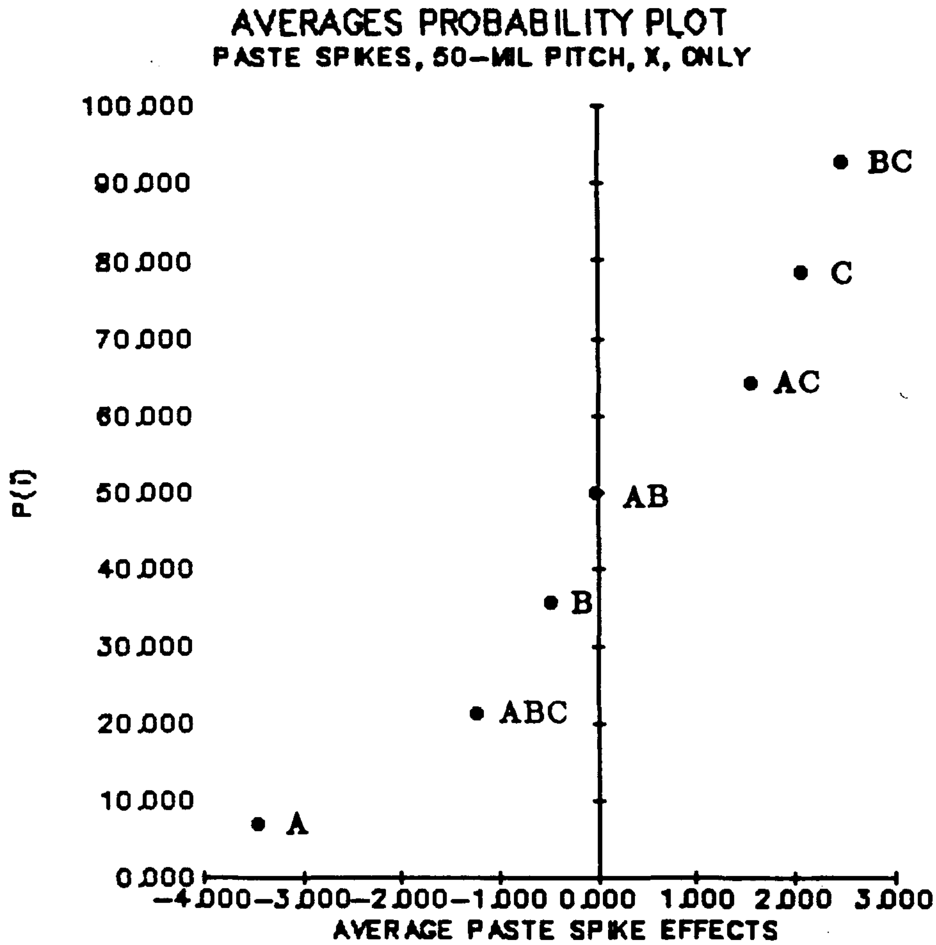

Figure 40. Normal Plot Solder Paste Spikes, LCC Parallel Pads

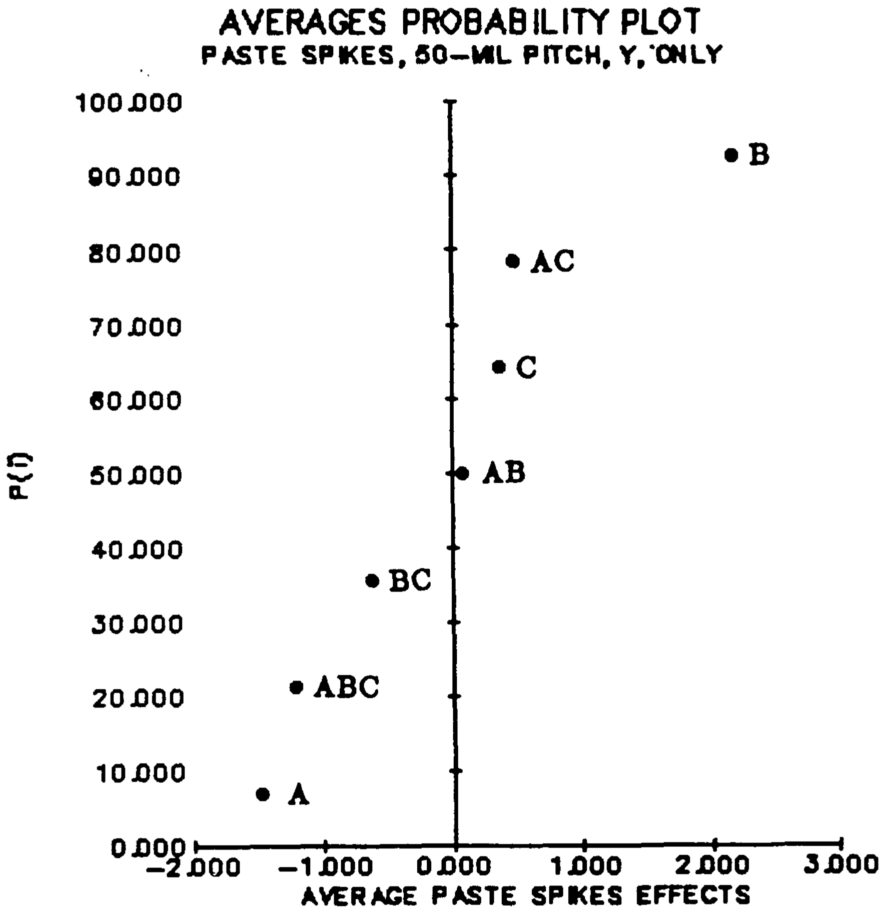

Figure 41. Normal Plot Solder Paste Spikes, LCC Perpendicular Pads

2.5.4.2 ANOVA

2.5.4.3 Capability Indices

Tables 101 through 104 present the ANOVA data for the Solder Paste Spikes response for the FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular pads, respectively. Tables 105 through 108 present the Cpk and yield data for this response variable for the FPD parallel, FPD perpendicular, LCC parallel, and LCC perpendicular pads, respectively. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

Table 101. ANOVA Table Solder Paste Spikes, FPD Parallel Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	30.61531	1	30.61531	51.12	0.00	77.7%
2		P	FID STRET	1.320312	1	1.320312	NA	NA	0.0%
3		P	PWB STYLE	0.007812	1	0.007812	NA	NA	0.0%
4			ERROR	5.040312	1	5.040312	8.417	0.03	11.5%
5		P	ERROR	0.000312	1	0.000312	NA	NA	0.0%
6		P	ERROR	1.402812	1	1.402812	NA	NA	0.0%
7		P	ERROR	0.262812	1	0.262812	NA	NA	0.0%
POOLED ERROR:				2.994062	5	0.598812			10.3%
TOTAL (CORRECTED):				38.64968	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 6.77 6 SIGMA ----> 7.48

Table 102. ANOVA Table Solder Paste Spikes, FPD Perpendicular Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	7.22	1	7.22	41.31	0.00	62.8%
2		P	FID STRET	0.02	1	0.02	NA	NA	0.0%
3			PWB STYLE	3.125	1	3.125	17.88	0.01	26.3%
4		P	ERROR	0.01125	1	0.01125	NA	NA	0.0%
5		P	ERROR	0.45125	1	0.45125	NA	NA	0.0%
6		P	ERROR	0.21125	1	0.21125	NA	NA	0.0%
7		P	ERROR	0.18	1	0.18	NA	NA	0.0%
POOLED ERROR:				0.87375	5	0.17475			10.9%
TOTAL (CORRECTED):				11.21875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 4.51 6 SIGMA ----> 4.04

Table 103. ANOVA Table Solder Paste Spikes, LCC Parallel Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	23.97781	1	23.97781	100.8	0.01	44.4%
2		P	FID STRET	0.475312	1	0.475312	NA	NA	0.0%
3			PWB STYLE	8.715312	1	8.715312	36.64	0.02	15.8%
4		P	ERROR	0.000312	1	0.000312	NA	NA	0.0%
5			ERROR	4.882812	1	4.882812	20.53	0.04	8.7%
6			ERROR	12.37531	1	12.37531	52.03	0.02	22.7%
7			ERROR	3.062812	1	3.062812	12.87	0.07	5.3%
POOLED ERROR:				0.475625	2	0.237812			3.1%
TOTAL(CORRECTED):				53.48968	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 8.83 6 SIGMA ----> 7.77

Table 104. ANOVA Table Solder Paste Spikes, LCC Perpendicular Pads

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	4.35125	1	4.35125	4.806	0.08	18.8%
2			FID STRET	9.46125	1	9.46125	10.45	0.02	46.7%
3		P	PWB STYLE	0.28125	1	0.28125	NA	NA	0.0%
4		P	ERROR	0.01125	1	0.01125	NA	NA	0.0%
5		P	ERROR	0.45125	1	0.45125	NA	NA	0.0%
6		P	ERROR	0.78125	1	0.78125	NA	NA	0.0%
7		P	ERROR	3.00125	1	3.00125	NA	NA	0.0%
POOLED ERROR:				4.52625	5	0.90525			34.6%
TOTAL(CORRECTED):				18.33875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 10.71 6 SIGMA ----> 6.68

Table 105. Cpk Table Solder Paste Spikes, FPD Parallel Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD, 0-6	0.000	6.000	4.510	4.040

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
9.0200	1.4851	0.7376	2.213

2*(USL-X(BAR))	YIELD:
2.9800	97.32%

Table 106. Cpk Table Solder Paste Spikes, FPD Perpendicular Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD, 0-6	0.000	6.000	6.770	7.480

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
13.5400	0.8021	-0.2059	-0.618

2*(USL-X(BAR))	YIELD:
-1.5400	0%, ESSENTIALLY

Table 107. Cpk Table Solder Paste Spikes, LCC Parallel Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
LCC, 0-12	0.000	12.000	8.830	7.770

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
17.6600	1.5444	0.8160	2.448

2*(USL-X(BAR))	YIELD:
6.3400	98.56%

Table 108. Cpk Table Solder Paste Spikes, LCC Perpendicular Pads

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
LCC, 0-12	0.000	12.000	10.710	6.680

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
21.4200	1.7964	0.3862	1.159

2*(USL-X(BAR))	YIELD:
2.5800	75.31%

2.5.4.4 Discussion of Paste Deposit Spikes

An examination of the data and analysis for both the LCC and FPD solder paste spike response variables reveals that the solder paste vendor has the highest probability of being a significant process variable for both LCC and FPD pad orientations. The ANOVA table indicates that the PWB style is a significant variable for the parallel FPD pads, only. Fiducial stretch appears with some probability of being a significant process variable for the LCC perpendicular pads. This latter process variable effect does not make much sense.

2.5.5 Final Run Process Variables

Fiducial stretch will not be incorporated into the final run as a controlled process variable, because it has not appeared in these studies as having any significant influence on the solder paste placement response variables.

The design of the stencil has been changed to reduce the size relative to the PWB pad patterns. In this set of experiments, the stencil openings matched the pad operints, and we felt that this allowed paste to extrude out onto the PWB from the gap between the stencil aperture and the PWB pad. The interference between the aperture and pad has been set to be 2 mil along the edges.

2.5.6 Subtask 5, Experiment 2 – Component Placement

The details of the component placement experiment are presented in Appendix F. The thrust of the experiment is presented in Figure 42. With the exception of the lead penetration response, all of the response data for all of the responses have been collected and reduced and are presented in the report. The lead penetration response data will be reported on in the final report to this program.

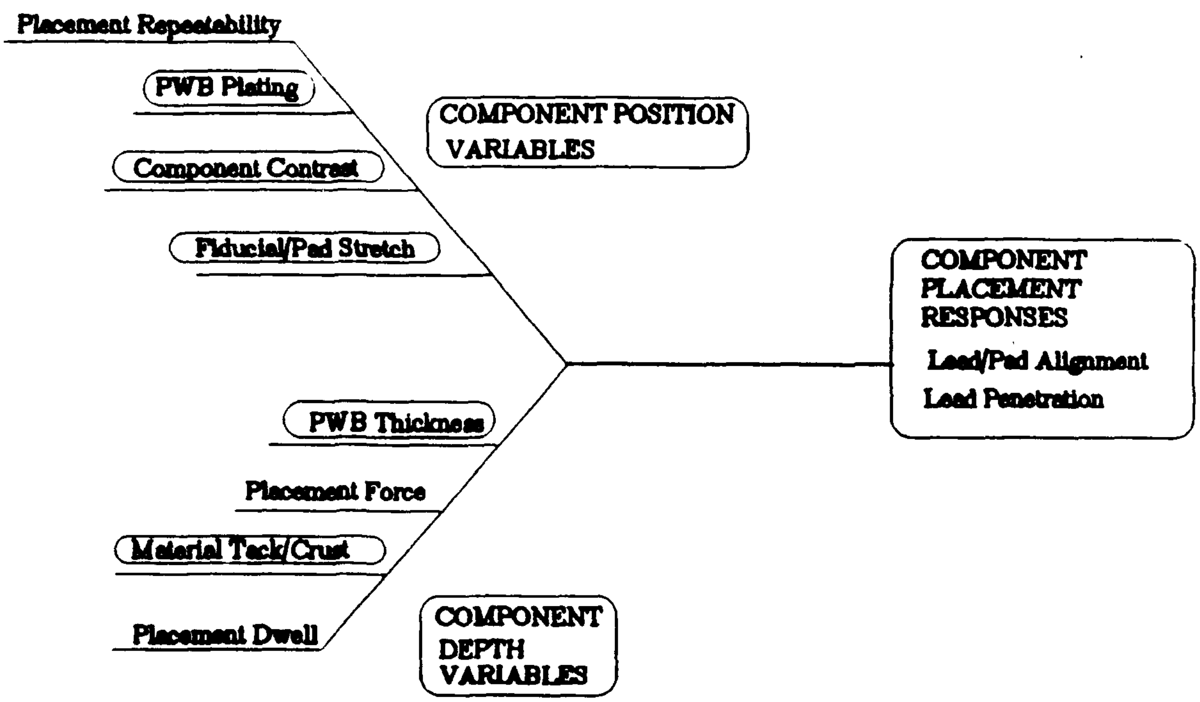

Figure 42. Component Placement Subtask Cause and Effect Diagram

This subtask involved three eight-run experiments in seven process variables. Two of the experiments were replications run to determine the variability of the process. The third experiment was a reflection of the replicates, and it was run to determine whether interactions existed among the process variables.

2.5.6.1 FPD Component Registration

The data for the FPD component registration response is presented in the following order: registration of side 1, side 2, side 3, and side 4. Registration is the measure of the difference between the center line of the FPD package lead and the center line of its associated footprint pad.

2.5.6.1.1 Effects

2.5.6.1.1.1 Analysis. The effects of the three process variables on the response variables, FPD Component Registration side 1, side 2, side 3, and side 4 are presented in Tables 109 through 112, respectively. Figures 43 through 46 are the normal plots of the ranked effects taken from Table 109 through 112, respectively. The corresponding effects tables for the folded design and the interaction tables are presented in Tables 113 through 120, inclusive. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.5.6.1.2 ANOVA

2.5.6.1.3 Capability Indices

Tables 121 through 124 present the ANOVA data for the FPD component registration response for the side 1, side 2, side 3, and side 4 of the PPD package, respectively. Tables 125 through 128 present the Cpk and yield data for this response variable for sides 1, 2, 3, and 4 of the PPD package, respectively. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.5.6.1.4 Discussion of FPD Component Registration

An examination of the data and analysis for the FPD component registration response variable indicate that, except for side 4, the effect due to the fiducial stretch process variable is a statistically significant value. This should not be the case since the vision system on the Gelzer robot utilizes a local fiducial to fine tune the fine pitch device placement. It was learned during the course of this experiment that the vision system was having a problem with the local fiducial. This problem was due to the fact that there was a plated through hole in the center of the fiducial pattern as well as a circuit trace connecting to the fiducial pad. The vision system can best recognize a circular pad that has no plated through holes not circuits running to it. The final experiment is using boards that were redesigned to accommodate this special requirement.

The Cpk tables indicate that, except for side 4 of the FPDs, the placement yield is not too bad. Side 4 is not at all acceptable. This low yield problem is being addressed by the incorporation of the redesigned local fiducial pattern.

2.5.6.2 LCC Component Registration

The data for the LCC component registration response is presented in the following order: registration of side 1, side 2, side 3, and side 4. Registration is the measure of the difference between the center line of the FPD package lead and the center line of its associated footprint pad.

Table 109. Effects Table, Normal Design FPD Component Registration, Side 1

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	-0.8	2.4	0.800	0.800		0.800		0.800			0.800		0.800		0.800	0.800	
2	-1.3	1.9	0.300	0.300		0.300			0.300		0.300	0.300		0.300			0.300
3	-2.2	0.5	-0.850	-0.850			-0.850	-0.850		-0.850			-0.850	-0.850			-0.850
4	5.5	3.1	4.300	4.300			4.300		4.300	4.300		4.300			4.300	4.300	
5	-1.2	4.9	1.850		1.850	1.850		1.850		1.850		1.850			1.850		1.850
6	-2.7	1.9	-0.400		-0.400	-0.400			-0.400	-0.400			-0.400	-0.400		-0.400	
7	2.1	5.3	3.700		3.700		3.700	3.700			3.700	3.700		3.700		3.700	
8	2.7	4.3	3.500		3.500		3.500		3.500		3.500		3.500		3.500		3.500
Total			13.20	4.55	8.65	2.55	10.65	5.50	7.70	4.90	8.30	10.15	3.05	2.75	10.45	8.40	4.80
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.650	1.138	2.163	0.638	2.663	1.375	1.925	1.225	2.075	2.538	0.763	0.688	2.613	2.100	1.200
Averages Effect (1<2>-1<1>)				1.025		2.025		0.550		0.850		-1.775		1.925		-0.900	

Table 110. Effects Table, Normal Design FPD Component Registration, Side 2

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	5.2	11.3	8.250	8.250		8.250		8.250			8.250		8.250		8.250	8.250	
2	6.2	8.5	7.350	7.350		7.350			7.350		7.350	7.350		7.350			7.350
3	9.1	8.7	8.900	8.900			8.900	8.900		8.900			8.900	8.900			8.900
4	10.9	11.2	11.050	11.050			11.050		11.050	11.050		11.050			11.050	11.050	
5	4.8	11.1	7.950		7.950	7.950		7.950		7.950		7.950			7.950		7.950
6	-1.5	12.6	5.550		5.550	5.550			5.550	5.550			5.550	5.550		5.550	
7	10.3	12.1	11.200		11.200		11.200	11.200			11.200	11.200		11.200		11.200	
8	8.5	12.1	10.300		10.300		10.300		10.300		10.300		10.300		10.300		10.300
Total			70.55	35.55	35.00	29.10	41.45	36.30	34.25	33.45	37.10	37.55	33.00	33.00	37.55	36.05	34.50
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			8.819	8.888	8.750	7.275	10.363	9.075	8.563	8.363	9.275	9.388	8.250	8.250	9.388	9.013	8.625
Averages Effect (l(2)-l(1))				-0.137		3.088		-0.512		0.913		-1.137		1.137		-0.387	

Table 111. Effects Table, Normal Design FPD Component Registration, Side 3

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	-2.6	-4.8	-3.700	-3.700		-3.700		-3.700			-3.700		-3.700		-3.700	-3.700	
2	-0.6	-3.7	-2.150	-2.150		-2.150			-2.150		-2.150	-2.150		-2.150			-2.150
3	-4.5	-1.3	-2.900	-2.900			-2.900	-2.900		-2.900			-2.900	-2.900			-2.900
4	-2.3	-2.4	-2.350	-2.350			-2.350		-2.350	-2.350		-2.350			-2.350	-2.350	
5	-2.2	-1.4	-1.800		-1.800	-1.800		-1.800		-1.800		-1.800			-1.800		-1.800
6	5	-1	2.000		2.000	2.000			2.000	2.000			2.000	2.000		2.000	
7	-4.6	-1.5	-3.050		-3.050		-3.050	-3.050			-3.050	-3.050		-3.050		-3.050	
8	-2.6	-1.4	-2.000		-2.000		-2.000		-2.000		-2.000		-2.000		-2.000		-2.000
Total			-15.95	-11.10	-4.85	-5.65	-10.30	-11.45	-4.50	-5.05	-10.90	-9.35	-6.60	-6.10	-9.85	-7.10	-8.85
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			-1.994	-2.775	-1.213	-1.413	-2.575	-2.863	-1.125	-1.263	-2.725	-2.338	-1.650	-1.525	-2.463	-1.775	-2.213
Averages Effect (1<2>-1<1>)				1.563		-1.163		1.738		-1.462		0.688		-0.938		-0.438	

Table 112. Effects Table, Normal Design FPD Component Registration, Side 4

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	2.8	2.4	2.600	2.600		2.600		2.600			2.600		2.600		2.600	2.600	
2	3.6	6.7	5.150	5.150		5.150			5.150		5.150	5.150		5.150			5.150
3	4.5	5.7	5.100	5.100			5.100	5.100		5.100			5.100	5.100			5.100
4	0.7	3.8	2.250	2.250			2.250		2.250	2.250		2.250			2.250	2.250	
5	2.7	0.6	1.650		1.650	1.650		1.650		1.650		1.650			1.650		1.650
6	5.1	3.4	4.250		4.250	4.250			4.250	4.250			4.250	4.250		4.250	
7	1.6	3.6	2.600		2.600		2.600	2.600			2.600	2.600		2.600		2.600	
8	2.8	4	3.400		3.400		3.400		3.400		3.400		3.400		3.400		3.400
Total			27.00	15.10	11.90	13.65	13.35	11.95	15.05	13.25	13.75	11.65	15.35	17.10	9.90	11.70	15.30
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			3.375	3.775	2.975	3.413	3.338	2.988	3.763	3.313	3.438	2.913	3.838	4.275	2.475	2.925	3.825
Averages Effect (1<2>-1<1>)				-0.800		-0.075		0.775		0.125		0.925		-1.800		0.900	

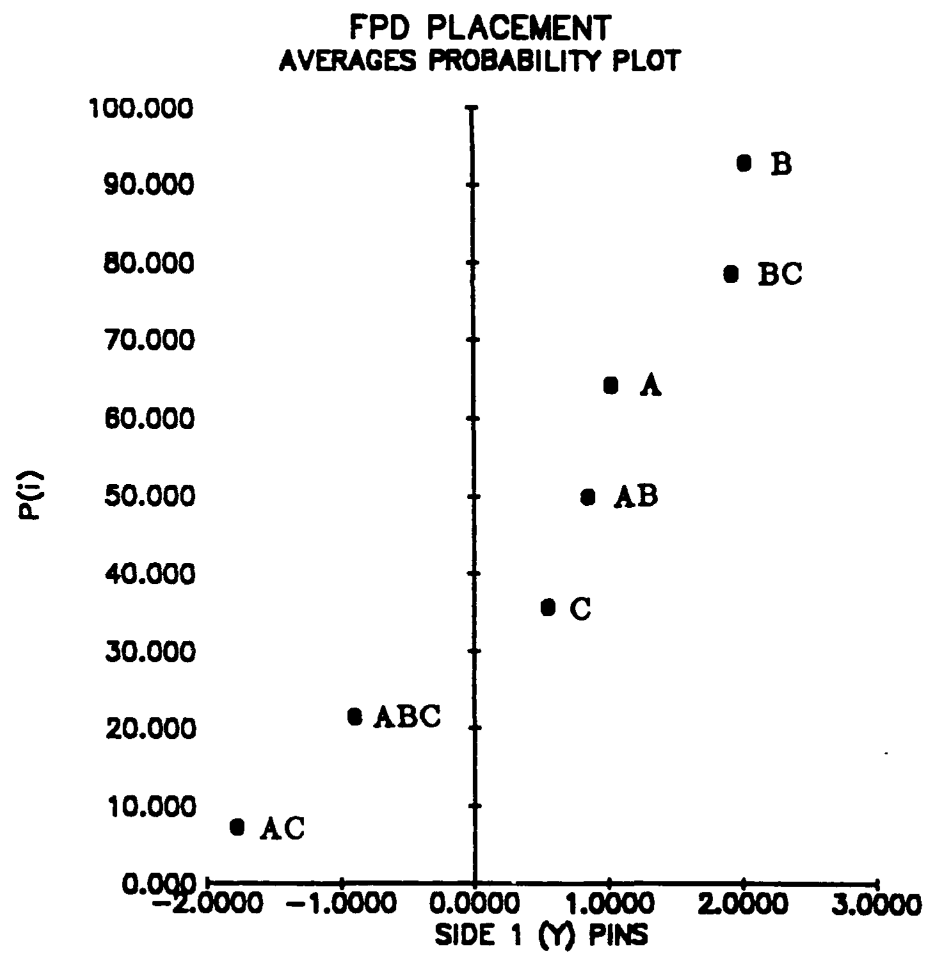

Figure 43. Normal Plot FPD Component Registration, Side 1

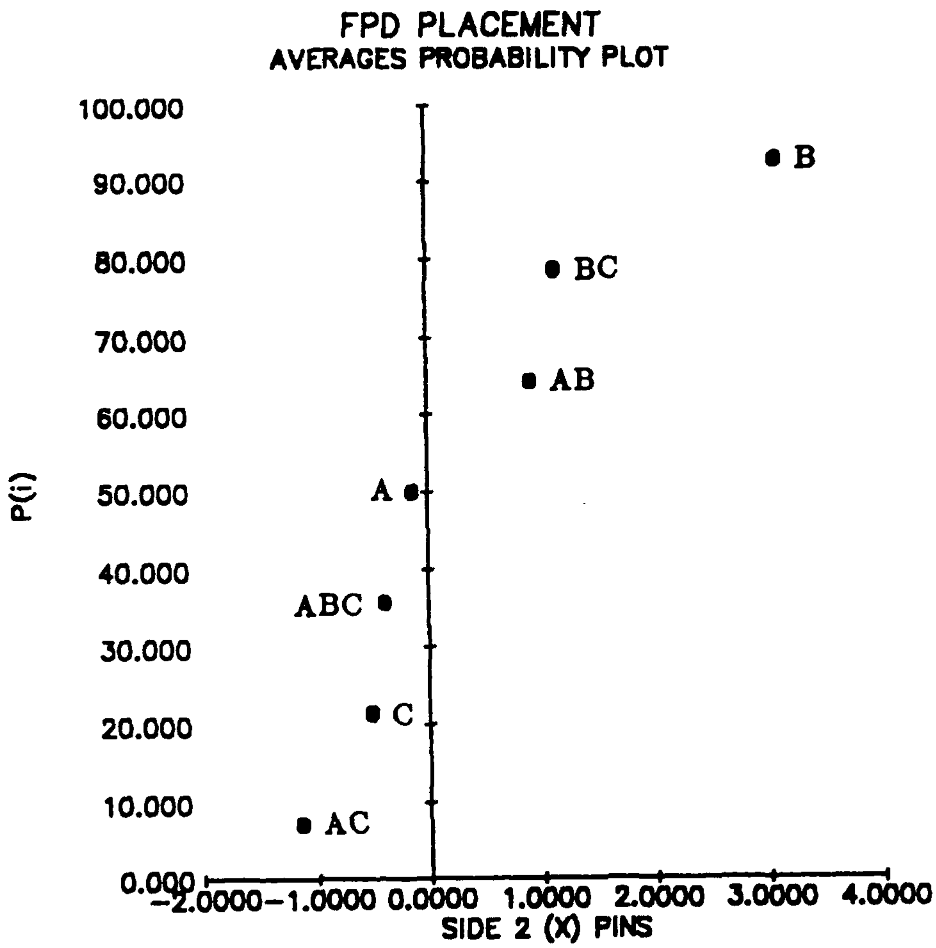

Figure 44. Normal Plot FPD Component Registration, Side 2

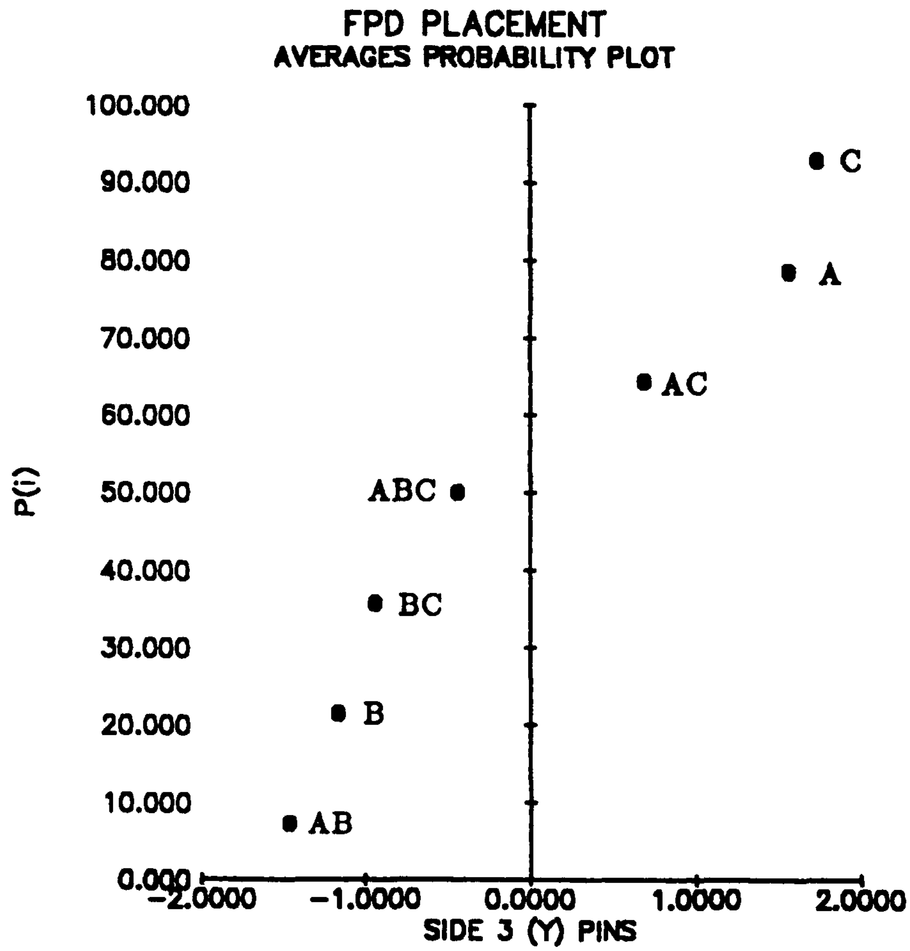

Figure 45. Normal Plot FPD Component Registration, Side 3

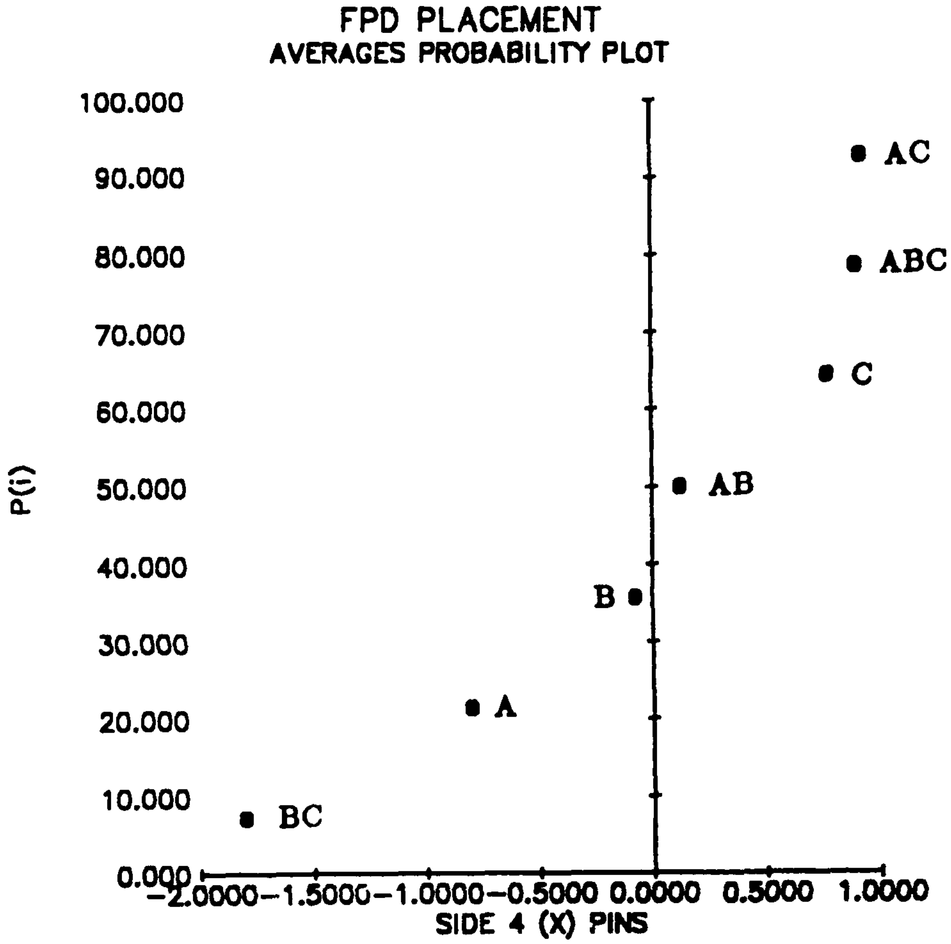

Figure 46. Normal Plot FPD Component Registration, Side 4

Table 113. Effects Table, Folded Design FPD Component Registration, Side 1

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	1.15		1.15		1.15		1.15	1.15		1.15		1.15			1.15
2	0.35		0.35		0.35	0.35		0.35			0.35		0.35	0.35	
3	1.95		1.95	1.95			1.95		1.95	1.95			1.95	1.95	
4	4.05		4.05	4.05		4.05			4.05		4.05	4.05			4.05
5	6.4	6.40			6.40		6.40		6.40		6.40	6.40		6.40	
6	5.2	5.20			5.20	5.20			5.20	5.20			5.20		5.20
7	4.75	4.75		4.75			4.75	4.75			4.75		4.75		4.75
8	0.6	0.60		0.60		0.60		0.60		0.60		0.60		0.60	
Total	24.45	16.95	7.50	11.35	13.10	10.20	14.25	6.85	17.60	8.90	15.55	12.20	12.25	9.30	15.15
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	3.06	4.24	1.88	2.84	3.28	2.55	3.56	1.71	4.40	2.23	3.89	3.05	3.06	2.33	3.79
Effect		-2.36		0.44		1.01		2.69		1.66		0.01		1.46	

Table 114. Effects Table, Folded Design FPD Component Registration, Side 2

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	9.1		9.10		9.10		9.10	9.10		9.10		9.10			9.10
2	8.8		8.80		8.80	8.80		8.80			8.80		8.80	8.80	
3	9.4		9.40	9.40			9.40		9.40	9.40			9.40	9.40	
4	10.15		10.15	10.15		10.15			10.15		10.15	10.15			10.15
5	10.75	10.75			10.75		10.75		10.75		10.75	10.75		10.75	
6	12.6	12.60			12.60	12.60			12.60	12.60			12.60		12.60
7	9.45	9.45		9.45			9.45	9.45			9.45		9.45		9.45
8	9.6	9.60		9.60		9.60		9.60		9.60		9.60		9.60	
Total	79.85	42.40	37.45	38.60	41.25	41.15	38.70	36.95	42.90	40.70	39.15	39.60	40.25	38.55	41.30
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	9.98	10.60	9.36	9.65	10.31	10.29	9.68	9.24	10.73	10.18	9.79	9.90	10.06	9.64	10.33
Effect		-1.24		0.66		-0.61		1.49		-0.39		0.16		0.69	

Table 115. Effects Table, Folded Design FPD Component Registration, Side 3

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC *************	
1	-1.4		-1.40		-1.40		-1.40	-1.40		-1.40		-1.40			-1.40
2	-1.05		-1.05		-1.05	-1.05		-1.05			-1.05		-1.05	-1.05	
3	-0.9		-0.90	-0.90			-0.90		-0.90	-0.90			-0.90	-0.90	
4	-3.8		-3.80	-3.80		-3.80			-3.80		-3.80	-3.80			-3.80
5	2	2.00			2.00		2.00		2.00		2.00	2.00		2.00	
6	-2	-2.00			-2.00	-2.00			-2.00	-2.00			-2.00		-2.00
7	1.05	1.05		1.05			1.05	1.05			1.05		1.05		1.05
8	-0.95	-0.95		-0.95		-0.95		-0.95		-0.95		-0.95		-0.95	
Total	-7.05	0.10	-7.15	-4.60	-2.45	-7.80	0.75	-2.35	-4.70	-5.25	-1.80	-4.15	-2.90	-0.90	-6.15
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	-0.88	0.03	-1.79	-1.15	-0.61	-1.95	0.19	-0.59	-1.18	-1.31	-0.45	-1.04	-0.73	-0.23	-1.54
Effect		-1.81		0.54		2.14		-0.59		0.86		0.31		-1.31	

Table 116. Effects Table, Folded Design Component Registration, Side 4

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	5		5.00		5.00		5.00	5.00		5.00		5.00			5.00
2	4.95		4.95		4.95	4.95		4.95			4.95		4.95	4.95	
3	2.4		2.40	2.40			2.40		2.40	2.40			2.40	2.40	
4	1.7		1.70	1.70		1.70			1.70		1.70	1.70			1.70
5	3.6	3.60			3.60		3.60		3.60		3.60	3.60		3.60	
6	2.2	2.20			2.20	2.20			2.20	2.20			2.20		2.20
7	5.6	5.60		5.60			5.60	5.60			5.60		5.60		5.60
8	5.5	5.50		5.50		5.50		5.50		5.50		5.50		5.50	
Total	30.95	16.90	14.05	15.20	15.75	14.35	16.60	21.05	9.90	15.10	15.85	15.80	15.15	16.45	14.50
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	3.87	4.23	3.51	3.80	3.94	3.59	4.15	5.26	2.48	3.78	3.96	3.95	3.79	4.11	3.63
Effect		-0.71		0.14		0.56		-2.79		0.19		-0.16		-0.49	

Table 117. Interaction Table FPD Component Registration, Side 1

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	13.20	24.45	18.83	-5.63
A	1.025	-2.36	-0.67	1.69
B	2.025	0.44	1.23	0.79
C	0.550	1.01	0.78	-0.23
AB	0.850	2.69	1.77	-0.92
AC	-1.775	1.66	-0.06	-1.72
BC	1.925	0.01	0.97	0.96
ABC	-0.900	1.46	0.28	-1.18

Table 118. Interaction Table FPD Component Registration, Side 2

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	70.75	79.85	75.30	-4.55
A	-0.138	-1.24	-0.69	0.55
B	3.088	0.66	1.87	1.21
C	-0.513	-0.61	-0.56	0.05
AB	0.913	1.49	1.20	-0.29
AC	-1.138	-0.39	-0.76	-0.37
BC	1.138	0.16	0.65	0.49
ABC	-0.388	0.69	0.15	-0.54

Table 119. Interaction Table FPD Component Registration, Side 3

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	-15.95	-7.05	-11.50	-4.45
A	1.563	-1.81	-0.12	1.69
B	-1.163	0.54	-0.31	-0.85
C	1.738	2.14	1.94	-0.20
AB	-1.463	-0.59	-1.03	-0.44
AC	0.688	0.86	0.77	-0.09
BC	-0.938	0.31	-0.31	-0.62
ABC	-0.438	-1.31	-0.87	0.44

Table 120. Interaction Table FPD Component Registration, Side 4

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	27.00	30.95	28.98	-1.97
A	-0.800	-0.71	-0.76	-0.05
B	-0.075	0.14	0.03	-0.11
C	0.775	0.56	0.67	0.11
AB	0.125	-2.79	-1.33	1.46
AC	0.925	0.19	0.56	0.37
BC	-1.800	-0.16	-0.98	-0.82
ABC	0.900	-0.49	0.21	0.70

Table 121. ANOVA Table FPD Component Registration, Side 1

|----ANOVA FOR MEAN(n=1), POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	2.10125	1	2.10125	NA	NA	0.0%
2			FID STRET	8.20125	1	8.20125	5.684	0.09	24.4%
3		P	PWB STYLE	0.605	1	0.605	NA	NA	0.0%
4		P	ERROR	1.445	1	1.445	NA	NA	0.0%
5			ERROR	6.30125	1	6.30125	4.367	0.10	17.5%
6			ERROR	7.41125	1	7.41125	5.136	0.09	21.6%
7		P	ERROR	1.62	1	1.62	NA	NA	0.0%
POOLED ERROR:				5.77125	4	1.442812			36.5%
TOTAL(CORRECTED):				27.685	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 1.65 6 SIGMA ---> 8.34

Table 122. ANOVA Table FPD Component Registration, Side 2

|----ANOVA FOR MEAN(n=1), POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	0.037812	1	0.037812	NA	NA	0.0%
2			FID STRET	19.06531	1	19.06531	14.84	0.01	66.4%
3		P	PWB STYLE	0.525312	1	0.525312	NA	NA	0.0%
4		P	ERROR	1.665312	1	1.665312	NA	NA	0.0%
5		P	ERROR	2.587812	1	2.587812	NA	NA	0.0%
6		P	ERROR	2.587812	1	2.587812	NA	NA	0.0%
7		P	ERROR	0.300312	1	0.300312	NA	NA	0.0%
POOLED ERROR:				7.704375	6	1.284062			33.6%
TOTAL(CORRECTED):				26.76968	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 8.32 6 SIGMA ---> 9.0[illegible]

Table 123. ANOVA Table FPD Component Registration, Side 3

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	4.882812	1	4.882812	4.746	0.12	18.4%
2			FID STRET	2.702812	1	2.702812	2.627	0.20	8.0%
3			PWB STYLE	6.037812	1	6.037812	5.869	0.09	23.9%
4			ERROR	4.277812	1	4.277812	4.158	0.13	15.5%
5		P	ERROR	0.945312	1	0.945312	NA	NA	0.0%
6		P	ERROR	1.757812	1	1.757812	NA	NA	0.0%
7		P	ERROR	0.382812	1	0.382812	NA	NA	0.0%
POOLED ERROR:				3.085937	3	1.028645			34.3%
TOTAL(CORRECTED):				20.98718	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): -1.99 6 SIGMA ----> 7.13

Table 124. ANOVA Table FPD Component Registration, Side 4

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	1.28	1	1.28	60.23	0.01	10.2%
2		P	FID STRET	0.01125	1	0.01125	NA	NA	0.0%
3			PWB STYLE	1.20125	1	1.20125	56.52	0.01	9.6%
4		P	ERROR	0.03125	1	0.03125	NA	NA	0.0%
5			ERROR	1.71125	1	1.71125	80.52	0.01	13.7%
6			ERROR	6.48	1	6.48	304.9	0.00	52.4%
7			ERROR	1.62	1	1.62	76.23	0.01	13.0%
POOLED ERROR:				0.0425	2	0.02125			1.2%
TOTAL(CORRECTED):				12.335	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 3.33 6 SIGMA ----> 3.60

Table 125. Cpk Table FPD Component Registration, Side 1

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD SIDE 1 (Y) -5 TO 5, MILS	-5.000	5.000	1.650	8.340

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
13.3000	1.1990	0.8034	2.410

2*(USL-X(BAR))	YIELD:
6.7000	98.41%

Table 126. Cpk Table FPD Component Registration, Side 2

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD SIDE 2 (X) -5 TO 5, MILS	-5.000	5.000	8.820	8.000

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
27.6400	1.2500	-0.9550	-2.865

2*(USL-X(BAR))	YIELD:
-7.6400	0%, ESSENTIALLY

Table 127. Cpk Table FPD Component Registration, Side 3

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD SIDE 3 (Y) -5 TO 5. MILS	-5.000	5.000	-1.990	7.130

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
6.0200	1.4025	0.8443	2.533

2*(USL-X(BAR))	YIELD:
13.9800	98.87%

Table 128. Cpk Table FPD Component Registration, Side 4

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
FPD SIDE 4 (X) -5 TO 5. MILS	-5.000	5.000	3.380	3.600

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
16.7600	2.7778	0.9000	2.700

2*(USL-X(BAR))	YIELD:
3.2400	99.31%

2.5.6.2.1 Effects

2.5.6.2.1.1 Analysis. The effects of the three process variables on the response variables, LCC Component Registration side 1, side 2, side 3, and side 4 are presented in Tables 129 through 132, respectively. Figures 47 through 50 are the normal plots of the ranked effects taken from Tables 129 through 132, respectively. The corresponding effects tables for the folded experimental designs and the interaction tables are presented in Tables 133 through 140. A general explanation of response tables and normal plot figures is presented in paragraph 2.1.1.1.1.

2.5.6.2.2 ANOVA

2.5.6.2.3 Capability Indices. Tables 141 through 144 present the ANOVA data for the FPD component registration response for sides 1, 2, 3, and 4, respectively, of the package. Tables 145 through 148 present the Cpk and yield data for this response variable for sides 1, 2, 3, and 4 of the FPD package, respectively. Paragraph 2.1.1.3 explains the methodology behind the derivation of these types of tables.

2.5.6.2.4 Discussion of LCC Component Registration. An examination of the data and analysis for the LCC component registration response variable demonstrates, that with the exception of side 1, the PWB style process variable is a recurring factor that has some statistical strength in being an affect on the response variable.

The Cpk tables indicate that the yield of side 1 is not acceptable. This problem is being corrected by changing the routine for locating the PWB with machine vision. The global fiducials are being relocated to diagonal corners of the PWB rather than along one side. The net affect will be to correct for differences in stretch or shrinkage of the PWB that are inevitable. Because of the differences in the weave of the glass cloth that is used to manufacture the PWB laminates, the PWBs have different shrinkage factors along their sides. This was not accounted for in the location of the global fiducials used in the experiments described by this report. They will be utilized in the final run experiment.

Table 129. Effects Table, Normal Design LCC Component Registration, Side 1

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC *************	
1	-9.8	-7.9	-8.850	-8.850		-8.850		-8.850			-8.850		-8.850		-8.850	-8.850	
2	-5	-2.2	-3.600	-3.600		-3.600			-3.600		-3.600	-3.600		-3.600			-3.600
3	10.4	-7.6	1.400	1.400			1.400	1.400		1.400			1.400	1.400			1.400
4	-9.7	-10	-9.850	-9.850			-9.850		-9.850	-9.850		-9.850			-9.850	-9.850	
5	-8.4	-8.7	-8.550		-8.550	-8.550		-8.550		-8.550		-8.550			-8.550		-8.550
6	-7.2	-6.9	-7.050		-7.050	-7.050			-7.050	-7.050			-7.050	-7.050		-7.050	
7	-8.4	-7.9	-8.150		-8.150		-8.150	-8.150			-8.150	-8.150		-8.150		-8.150	
8	-12.4	-8.1	-10.250		-10.250		-10.250		-10.250		-10.250		-10.250		-10.250		-10.250
Total			-54.90	-20.90	-34.00	-28.05	-26.85	-24.15	-30.75	-24.05	-30.85	-30.15	-24.75	-17.40	-37.50	-33.90	-21.00
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			-6.863	-5.225	-8.500	-7.013	-6.713	-6.038	-7.688	-6.013	-7.713	-7.538	-6.188	-4.350	-9.375	-8.475	-5.250
Averages Effect (1<2>-1<1>)				-3.275		0.300		-1.650		-1.700		1.350		-5.025		3.225	

Table 130. Effects Table, Normal Design LCC Component Registration, Side 2

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Lead		PWB		Solder	Paste	PWB		Fiducial		INTERACTION AND			
Trial	Variables			Aging,	years	Type		Aging,	hours	Thickness,	milStretch			ERROR TERMS		**************	
No.	Normal	Replic	Avg.	0	1	air	fused	0.5	3	thick	thin	Str	Nominal				
1	4	4.3	4.150	4.150		4.150		4.150			4.150		4.150		4.150	4.150	
2	5.5	2.5	4.000	4.000		4.000			4.000		4.000	4.000		4.000			4.000
3	2.5	4.1	3.300	3.300			3.300	3.300		3.300			3.300	3.300			3.300
4	5.2	1.5	3.350	3.350			3.350		3.350	3.350		3.350			3.350	3.350	
5	4	-0.5	1.750		1.750	1.750		1.750		1.750		1.750			1.750		1.750
6	1.2	2.6	1.900		1.900	1.900			1.900	1.900			1.900	1.900		1.900	
7	0.4	2	1.200		1.200		1.200	1.200			1.200	1.200		1.200		1.200	
8	6.9	6.2	6.550		6.550		6.550		6.550		6.550		6.550		6.550		6.550
Total			26.20	14.80	11.40	11.80	14.40	10.40	15.80	10.30	15.90	10.30	15.90	10.40	15.80	10.60	15.60
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			3.275	3.700	2.850	2.950	3.600	2.600	3.950	2.575	3.975	2.575	3.975	2.600	3.950	2.650	3.900
Averages Effect (1<2>-1<1>)				-0.850		0.650		1.350		1.400		1.400		1.350		1.250	

Table 131. Effects Table, Normal Design LCC Component Registration, Side 3

Std Order Trial No.	Observed Response Variables Normal	Replic	Avg.	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	-8.1	-7.6	-7.850	-7.850		-7.850		-7.850			-7.850		-7.850		-7.850	-7.850	
2	-3	0.1	-1.450	-1.450		-1.450			-1.450		-1.450	-1.450		-1.450			-1.450
3	-8.6	-4.5	-6.550	-6.550			-6.550	-6.550		-6.550			-6.550	-6.550			-6.550
4	-6.1	-9.1	-7.600	-7.600			-7.600		-7.600	-7.600		-7.600			-7.600	-7.600	
5	-8.2	-8.1	-8.150		-8.150	-8.150		-8.150		-8.150		-8.150			-8.150		-8.150
6	-5.5	-5	-5.250		-5.250	-5.250			-5.250	-5.250			-5.250	-5.250		-5.250	
7	-8.8	-5.9	-7.350		-7.350		-7.350	-7.350			-7.350	-7.350		-7.350		-7.350	
8	-8.1	-6.2	-7.150		-7.150		-7.150		-7.150		-7.150		-7.150		-7.150		-7.150
Total			-51.35	-23.45	-27.90	-22.70	-28.65	-29.90	-21.45	-27.55	-23.80	-24.55	-26.80	-20.60	-30.75	-28.05	-23.30
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			-6.419	-5.862	-6.975	-5.675	-7.163	-7.475	-5.363	-6.888	-5.950	-6.138	-6.700	-5.150	-7.688	-7.013	-5.825
Averages Effect (1<2>-1<1>)				-1.113		-1.488		2.113		0.938		-0.563		-2.538		1.188	

Table 132. Effects Table, Normal Design LCC Component Registration, Side 4

Std				A		B		C		AB		AC		BC		ABC	
Order	Observed Response			Lead		PWB		Solder	Paste	PWB		Fiducial		INTERACTION AND			
Trial	Variables			Aging,	years	Type		Aging,	hours	Thickness,	mils	Stretch		ERROR TERMS		**************	
No.	Normal	Replic	Avg.	0	1	air	fused	0.5	3	thick	thin	Str	Nominal				
1	2.2	1.2	1.700	1.700		1.700		1.700			1.700		1.700		1.700	1.700	
2	8.3	1.1	4.700	4.700		4.700			4.700		4.700	4.700		4.700			4.700
3	0.3	-0.2	0.050	0.050			0.050	0.050		0.050			0.050	0.050			0.050
4	1.4	1.5	1.450	1.450			1.450		1.450	1.450		1.450			1.450	1.450	
5	4.6	-1	1.800		1.800	1.800		1.800		1.800		1.800			1.800		1.800
6	1.1	0.8	0.950		0.950	0.950			0.950	0.950			0.950	0.950		0.950	
7	0.5	0.1	0.300		0.300		0.300	0.300			0.300	0.300		0.300		0.300	
8	3.4	5.3	4.350		4.350		4.350		4.350		4.350		4.350		4.350		4.350
Total			15.30	7.90	7.40	9.15	6.15	3.85	11.45	4.25	11.05	8.25	7.05	6.00	9.30	4.40	10.90
No. of responses			8	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Responses Average			1.913	1.975	1.850	2.288	1.538	0.963	2.863	1.063	2.763	2.063	1.763	1.500	2.325	1.100	2.725
Averages Effect (1<2>-1<1>)				-0.125		-0.750		1.900		1.700		-0.300		0.825		1.625	

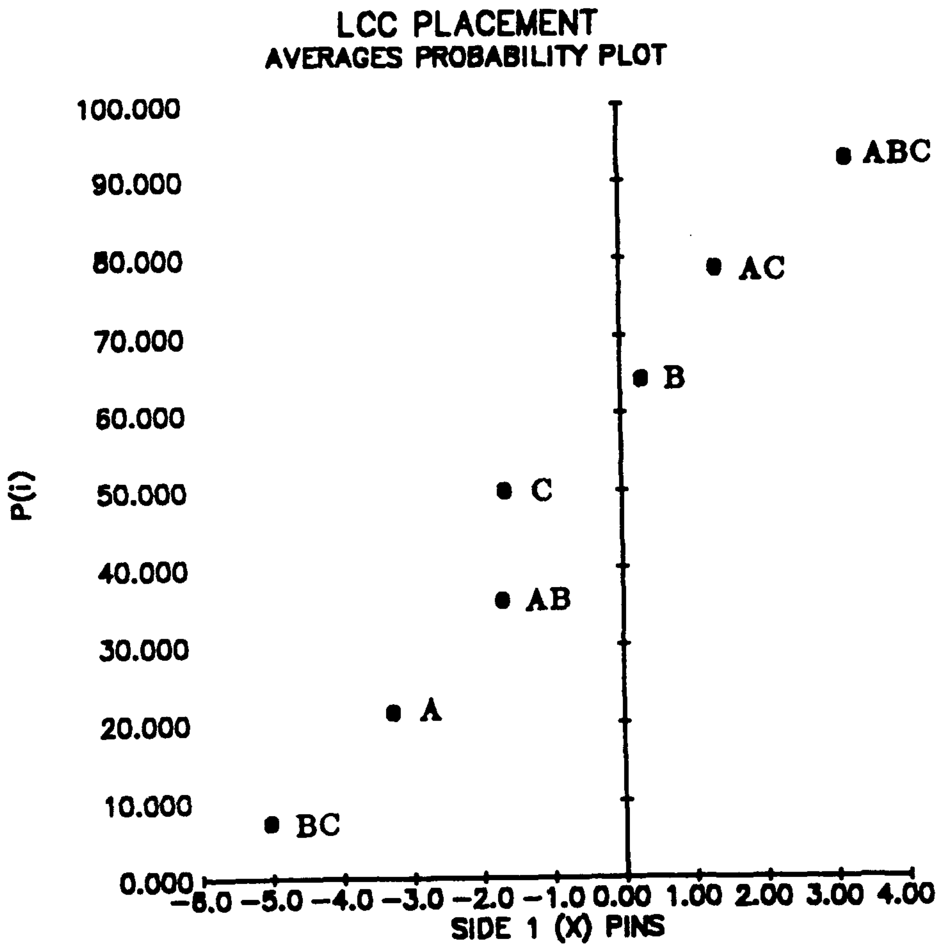

Figure 47. Normal Plot LCC Component Registration, Side 1

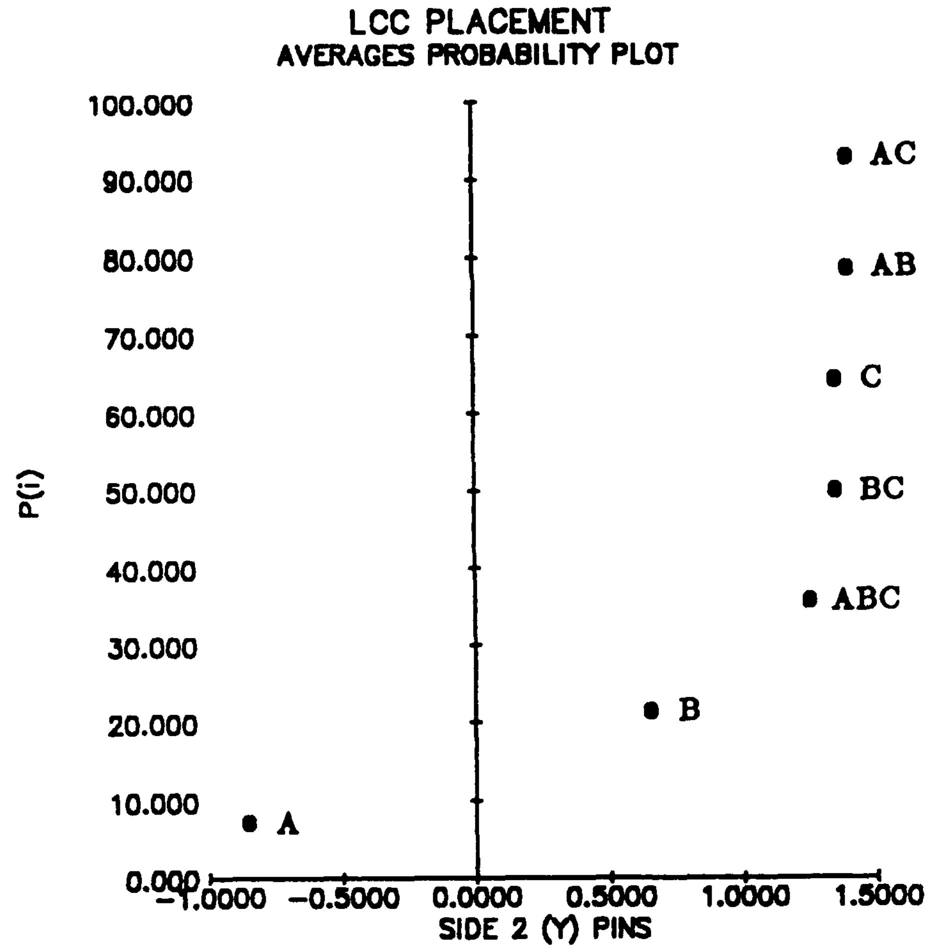

Figure 48. Normal Plot LCC Component Registration, Side 2

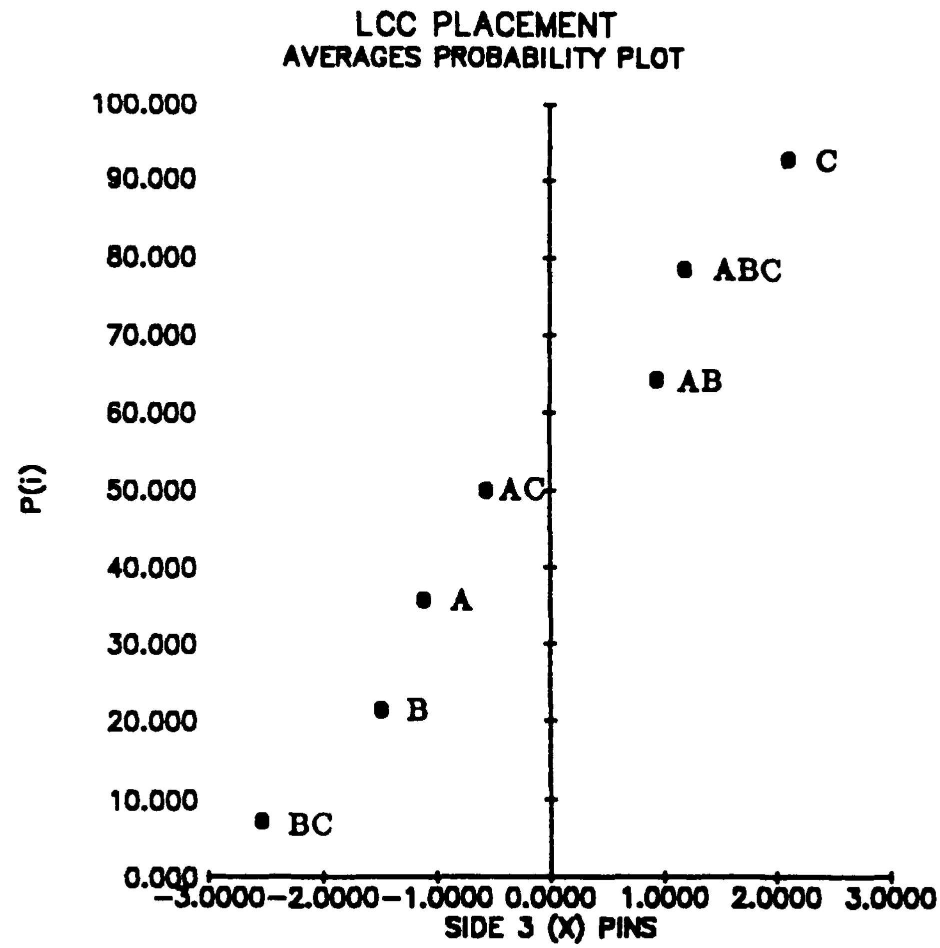

Figure 49. Normal Plot LCC Component Registration, Side 3

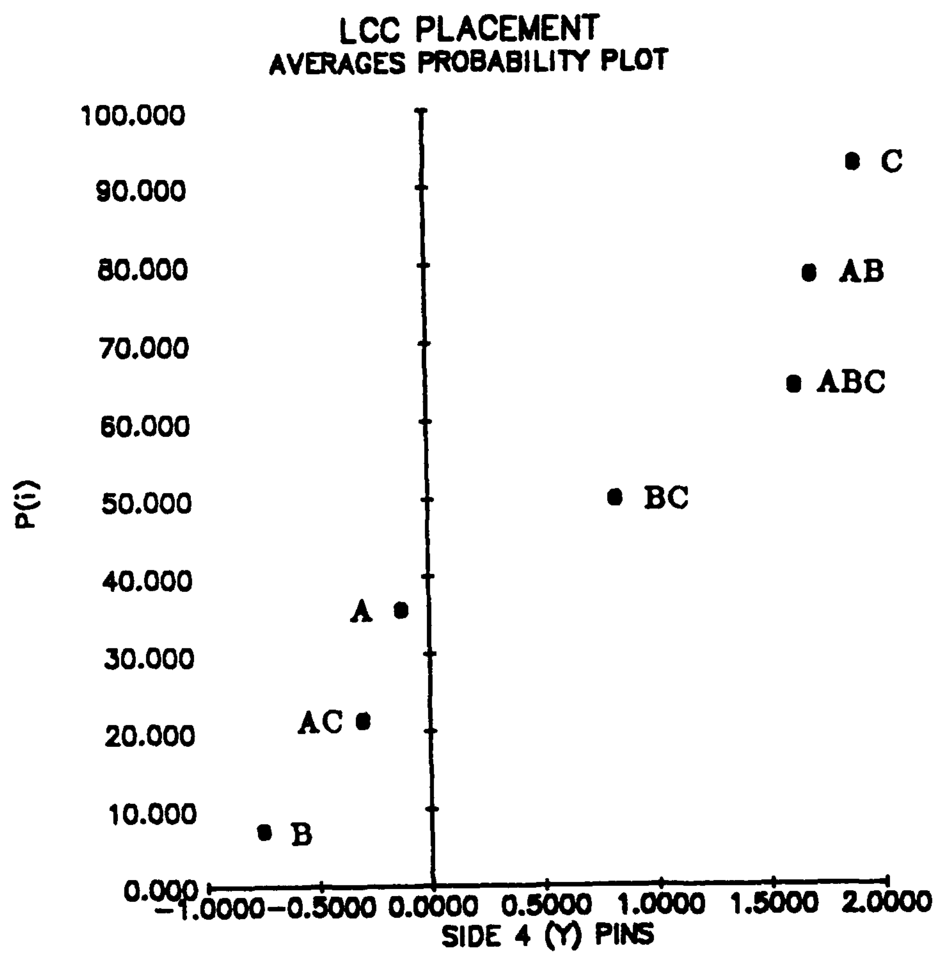

Figure 50. Normal Plot LCC Component Registration, Side 4

Table 133. Effects Table, Folded Design LCC Component Registration, Side 1

Std Order Trial No.	Resp Obs Values	A Lead Aging. years 0	1	B PWB Type air	fused	C Solder Paste Aging hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC *************	
1	-10.13		-10.13		-10.13		-10.13	-10.13		-10.13		-10.13			-10.13
2	-11.13		-17.13		-11.13	-11.13		-11.13			-11.13		-11.13	-11.13	
3	-3.925		-3.93	-3.93			-3.93		-3.93	-3.93			-3.93	-3.93	
4	-5.6		-5.60	-5.60		-5.60			-5.60		-5.60	-5.60			-5.60
5	-11.38	-11.38			-11.38		-11.38		-11.38		-11.38	-11.38		-11.38	
6	-11.35	-11.35			-11.35	-11.35			-11.35	-11.35			-11.35		-11.35
7	-6.875	-6.88		-6.88			-6.88	-6.88			-6.88		-6.88		-6.88
8	-8.45	-8.45		-8.45		-8.45		-8.45		-8.45		-8.45		-8.45	
Total	-68.83	-38.05	-30.78	-24.85	-43.98	-36.53	-32.30	-36.58	-32.25	-33.85	-34.98	-35.55	-33.28	-34.88	-33.95
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	-8.60	-9.51	-7.69	-6.21	-10.99	-9.13	-8.08	-9.14	-8.06	-8.46	-8.74	-8.89	-8.32	-8.72	-8.49
Effect		1.82		-4.78		1.06		1.08		-0.28		0.57		0.23	

Table 134. Effects Table, Folded Design LCC Component Registration, Side 2

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	A 1	B PWB Type air	B fused	C Solder Paste Aging, hours 0.5	C 3	AB PWB Thickness, mils thick	AB thin	AC Fiducial Stretch Str	AC Nominal	BC INTERACTION AND ERROR TERMS	BC	ABC **************	ABC
1	1.475		1.48		1.48		1.48	1.48		1.48		1.48			1.48
2	4.425		4.43		4.43	4.43		4.43			4.43		4.43	4.43	
3	2.925		2.93	2.93			2.93		2.93	2.93			2.93	2.93	
4	6.975		6.98	6.98		6.98			6.98		6.98	6.98			6.98
5	2.25	2.25			2.25		2.25		2.25		2.25	2.25		2.25	
6	2.15	2.15			2.15	2.15			2.15	2.15			2.15		2.15
7	7.775	7.78		7.78			7.78	7.78			7.78		7.78		7.78
8	-2.5	-2.50		-2.50		-2.50		-2.50		-2.50		-2.50		-2.50	
Total	25.47	9.68	15.80	15.17	10.30	11.05	14.43	11.18	14.30	4.05	21.43	8.20	17.28	7.10	18.38
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	3.18	2.42	3.95	3.79	2.58	2.76	3.61	2.79	3.58	1.01	5.36	2.05	4.32	1.78	4.59
Effect		1.53		-1.22		0.84		0.78		4.34		2.27		2.82	

Table 135. Effects Table, Folded Design LCC Component Registration, Side 3

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	-8.325		-8.33		-8 33		-8.33	-8.33		-8.33		-8.33			-8.33
2	-7.85		-7.85		-7.35	-7.85		-7.85			-7.85		-7.85	-7.85	
3	-1.925		-1.93	-1.93			-1.93		-1.93	-1.93			-1.93	-1.93	
4	-2.8		-2.80	-2.80		-2.80			-2.80		-2.80	-2.80			-2.80
5	-9.325	-9.33			-9.33		-9.33		-9.33		-9.33	-9.33		-9.33	
6	-8.275	-8.28			-8.28	-8.28			-8.28	-8.28			-8.28		-8.28
7	-4.5	-4.50		-4.50			-4.50	-4.50			-4.50		-4.50		-4.50
8	-6.45	-6.45		-6.45		-6.45		-6.45		-6.45		-6.45		-6.45	
Total	-49.45	-28.55	-20.90	-15.68	-33.78	-25.38	-24.08	-27.13	-22.33	-24.98	-24.48	-26.90	-22.55	-25.55	-23.90
No. of values	ɔ.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	-6.18	-7.14	-5.23	-3.92	-8.44	-6.34	-6.02	-6.78	-5.58	-6.24	-6.12	-6.73	-5.64	-6.39	-5.98
Effect		1.91		-4.53		0.32		1.20		0.13		1.09		0.41	

Table 136. Effects Table, Folded Design LCC Component Registration, Side 4

Std Order Trial No.	Resp Obs Values	A Lead Aging, years 0	1	B PWB Type air	fused	C Solder Paste Aging, hours 0.5	3	AB PWB Thickness, mils thick	thin	AC Fiducial Stretch Str	Nominal	BC INTERACTION AND ERROR TERMS		ABC **************	
1	0.9		0.90		0.90		0.90	0.90		0.90		0.90			0.90
2	3.075		3.08		3.08	3.08		3.08			3.08		3.08	3.08	
3	-0.025		-0.03	-0.03			-0.03		-0.03	-0.03			-0.03	-0.03	
4	4.9		4.90	4.90		4.90			4.90		4.90	4.90			4.90
5	0.45	0.45			0.45		0.45		0.45		0.45	0.45		0.45	
6	-0.375	-0.38			-0.38	-0.38			-0.38	-0.38			-0.38		-0.38
7	5.675	5.68		5.68			5.68	5.68			5.68		5.68		5.68
8	-0.125	-0.13		-0.13		-0.13		-0.13		-0.13		-0.13		-0.13	
Total	14.48	5.63	8.85	10.43	4.05	7.48	7.00	9.53	4.95	0.38	14.10	6.13	8.35	3.38	11.10
No. of values	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Average	1.81	1.41	2.21	2.61	1.01	1.87	1.75	2.38	1.24	0.09	3.53	1.53	2.09	0.84	2.78
Effect		0.81		-1.59		-0.12		-1.14		3.43		0.56		1.93	

Table 137. Interaction Table LCC Component Registration, Side 1

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	-54.90	-68.83	-61.87	6.97
A	-3.275	1.82	-0.73	-2.55
B	0.300	-4.78	-2.24	2.54
C	-1.650	1.06	-0.30	-1.36
AB	-1.700	1.08	-0.31	-1.39
AC	1.350	-0.28	0.54	0.82
BC	-5.025	0.57	-2.23	-2.80
ABC	3.225	0.23	1.73	1.50

Table 138. Interaction Table LCC Component Registration, Side 2

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	26.20	25.47	25.84	0.37
A	-0.850	1.53	0.34	-1.19
B	0.650	-1.22	-0.29	0.94
C	1.350	0.84	1.10	0.26
AB	1.400	0.78	1.09	0.31
AC	1.400	4.34	2.87	-1.47
BC	1.350	2.27	1.81	-0.46
ABC	1.250	2.82	2.04	-0.79

Table 139. Interaction Table LCC Component Registration, Side 3

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	-51.35	-49.45	-50.40	-0.95
A	-1.113	1.91	0.40	-1.51
B	-1.488	-4.53	-3.01	1.52
C	2.113	0.32	1.22	0.90
AB	0.938	1.2	1.07	-0.13
AC	-0.563	0.13	-0.22	-0.35
BC	-2.538	1.09	-0.72	-1.81
ABC	1.188	0.41	0.80	0.39

Table 140. Interaction Table LCC Component Registration, Side 4

Column	Normal E(1)	Reflect. E(2)	Main Effect (E(1)+E(2))/2	Interact. Effect (E(1)-E(2))/2
Y	15.30	14.48	14.89	0.41
A	-0.125	0.81	0.34	-0.47
B	-0.750	-1.59	-1.17	0.42
C	1.900	-0.12	0.89	1.01
AB	1.700	-1.14	0.28	1.42
AC	-0.300	3.43	1.57	-1.87
BC	0.825	0.56	0.69	0.13
ABC	1.625	1.93	1.78	-0.15

Table 141. ANOVA Table LCC Component Registration, Side 1

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	21.45125	1	21.45125	5.701	0.08	16.4%
2		P	FID STRET	0.18	1	0.18	NA	NA	0.0%
3		P	PWR STYLE	5.445	1	5.445	NA	NA	0.0%
4		P	ERROR	5.78	1	5.78	NA	NA	0.0%
5		P	ERROR	3.645	1	3.645	NA	NA	0.0%
6			ERROR	50.50125	1	50.50125	13.42	0.02	43.4%
7			ERROR	20.80125	1	20.80125	5.528	0.08	15.8%
POOLED ERROR:				15.05	4	3.7625			24.4%
TOTAL(CORRECTED):				107.8037	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): -6.88 6 SIGMA ----> 14.73

Table 142. ANOVA Table LCC Component Registration, Side 2

|----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------|

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	1.445	1	1.445	NA	NA	0.0%
2		P	FID STRET	0.845	1	0.845	NA	NA	0.0%
3			PWR STYLE	3.645	1	3.645	3.183	0.22	12.2%
4			ERROR	3.92	1	3.92	3.423	0.21	13.5%
5			ERROR	3.92	1	3.92	3.423	0.21	13.5%
6			ERROR	3.645	1	3.645	3.183	0.22	12.2%
7			ERROR	3.125	1	3.125	2.729	0.24	9.6%
POOLED ERROR:				2.29	2	1.145			39.0%
TOTAL(CORRECTED):				20.545	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 3.28 6 SIGMA ----> 7.33

Table 143. ANOVA Table LCC Component Registration, Side 3

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1			PASTE VEN	2.475312	1	2.475312	3.911	0.3[illegible]	5.4%
2			FID STRET	4.425312	1	4.425312	6.993	0.24	11.2%
3			PWB STYLE	8.925312	1	8.925312	14.10	0.17	24.5%
4			ERROR	1.757812	1	1.757812	2.777	0.35	3.3%
5		P	ERROR	0.632812	1	0.632812	NA	NA	0.0%
6			ERROR	12.87781	1	12.87781	20.35	0.15	36.1%
7			ERROR	2.820312	1	2.820312	4.456	0.29	6.5%
POOLED ERROR:				0.632812	1	0.632812			13.1%
TOTAL(CORRECTED):				33.91468	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): -6.42 6 SIGMA ----> 7.23

Table 144. ANOVA Table LCC Component Registration, Side 4

!----ANOVA FOR MEAN(n=1) , POOLED ERROR USED FOR F TESTS--------!

FACTOR	CD	PL	NAME	SS	DF	MS	F	PROB	%
1		P	PASTE VEN	0.03125	1	0.03125	NA	NA	0.0%
2		P	FID STRET	1.125	1	1.125	NA	NA	0.0%
3			PWB STYLE	7.22	1	7.22	10.70	0.03	31.2%
4			ERROR	5.78	1	5.78	8.570	0.04	24.3%
5		P	ERROR	0.18	1	0.18	NA	NA	0.0%
6		P	ERROR	1.36125	1	1.36125	NA	NA	0.0%
7			ERROR	5.28125	1	5.28125	7.831	0.05	22.0%
POOLED ERROR:				2.6975	4	0.674375			22.5%
TOTAL(CORRECTED):				20.97875	7				

NOTE: PROB VALUES LESS THAN 0.05 INDICATE SIGNIFICANCE AT ALPHA=0.05

X(BAR): 1.91 6 SIGMA ----> 6.37

Table 145. Cpk Table LCC Component Registration, Side 1

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
LCC SIDE 1 (X) -8.75 TO 8.75	-8.750	8.750	-6.860	14.730

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
3.7800	1.1881	0.2566	0.770

2*(USL-X(BAR))	YIELD:
31.2200	77.94%

Table 146. Cpk Table LCC Component Registration, Side 2

RESP VAR	SPEC LIMIT LOWER	UPPER	X(BAR)	6 SIGMA(total) TERM
LCC SIDE 2 (Y) -8.75 TO 8.75	-8.750	8.750	3.280	7.330

2*(X(BAR)-LSL)	CP	CPK	PROCESS SIGMA
24.0600	2.3874	1.4925	4.477

2*(USL-X(BAR))	YIELD:
10.9400	100%, ESSENTIALLY

Table 147. Cpk Table LCC Component Registration, Side 3

```
RESP              SPEC LIMIT
VAR              LOWER    UPPER    X(BAR) 6 SIGMA(total) TERM

LCC SIDE 3 (X) -8.750   8.750    -6.420        7.230
-8.75 TO 8.75

                                          PROCESS
2*(X(BAR)-LSL)            CP      CPK    SIGMA
   4.6600               2.4205  0.6445  1.934

2*(USL-X(BAR))          YIELD:
   30.3400                97.32%
```

Table 148. Cpk Table LCC Component Registration, Side 4

```
RESP              SPEC LIMIT
VAR              LOWER    UPPER    X(BAR) 6 SIGMA(total) TERM

LCC SIDE 4 (Y) -8.750   8.750    1.910         6.370
-8.75 TO 8.75

                                          PROCESS
2*(X(BAR)-LSL)            CP      CPK    SIGMA
   21.3200              2.7473  2.1476  6.443

2*(USL-X(BAR))          YIELD:
   13.6800              100%, ESSENTIALLY
```


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